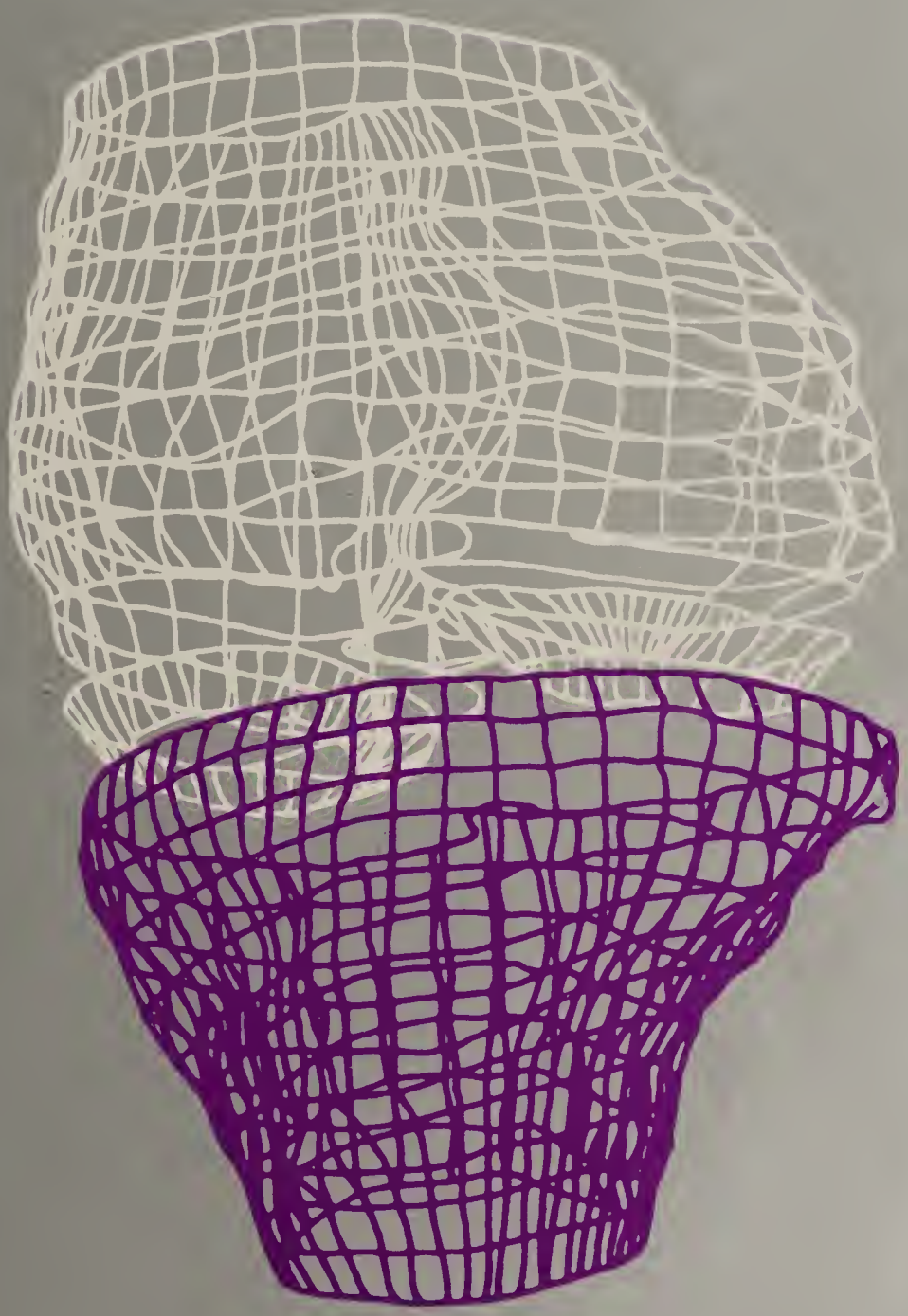
Veterans Administration

Rehabilitation R&D Progress Reports - 1983



Department of Medicine and Surgery
Rehabilitation R&D Service

Veterans Administration

Rehabilitation R&D Progress Reports 1983

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INFORMATION FOR PRINCIPAL INVESTIGATORS PROVIDING PROGRESS REPORTS FOR FUTURE ISSUES

We welcome contributions to Rehabilitation R&D Progress Reports. It is our desire to present a comprehensive view of research and progress, and we don't want significant work to be omitted.

Reports intended for future issues must be received at the Office of Technology Transfer in New York, in final form suitable for publication and ready for typesetting, by June 1 of each year. This will allow October mailing of future issues, as planned. It is hoped that contributing agencies and principal investigators will mark June 1 on their calendars as an ongoing, routine report period.

The text should contain a brief version of the research hypothesis, methodology, and preliminary findings and/or results since the last report. If the project is not completed, a brief comment on future plans or goals is appropriate. However, the entire report may not exceed 600 words. These reports are not meant to be, nor will they be handled as, short research papers. As discussed in the Editorial of this issue, the goal of this progress report publication is to facilitate access to sources of information, formal or informal, about scientific research and engineering development, both completed and ongoing. The progress reports will not be refereed and their contents will be solely the statements of the investigators.

If a research project has come to its conclusion, only a very brief final report should be supplied to Rehabilitation R&D Progress Reports. Scientific findings should be submitted to the Journal of Rehabilitation Research and Development or other appropriate scientific journal for publication as a scientific paper. (If such a paper has been submitted or is in press, include that information in your brief report.)

To facilitate publishing, please note the following requirements:

1. Type letter-quality, double-spaced on 8½x11 inch paper.
2. Leave 1-inch margin left and right.
3. Include investigator(s) name(s) with highest degree, position, organization, and location (full address and Zip of Principal Investigator).
4. Clearly indicate on the first page the source(s) of funding for the work described in the report and the location(s) of the actual research activity.
5. Number the pages visibly.
6. If use of a photo or drawing is essential to the reader's understanding of the research, it will be accepted. Use a glossy print 5x7 inches or larger, unmounted. Do not paste anything on a print — identify it lightly in pencil on the back. If your illustration is a line drawing, submit as a photostat or direct-positive print.
7. Charts, graphs, and graphic or numerical printouts of data should be supplied only when essential to an understanding of the report. It is expected that in almost all cases the use of data in the reports will be limited to brief quotation of sample preliminary figures, in text.
8. If a figure is provided, number it and cite it by number in the text.
9. If a photo shows a recognizable person, provide a copy of a release form signed by that individual (or a guardian, etc.); otherwise, we will be required to blank out that person's face in the photo.
10. References and/or bibliographies are acceptable if the investigator thinks they will serve to indicate the areas of science or technology drawn upon by the project, and will aid the reader in seeking further understanding of the problem under investigation.

The preferred method cites all references in the text by number and lists them numerically at the end of the report. (This need not preclude your use of authors' names and dates in the text in citing references, if you prefer.)

Address contributions to:

Editor
Rehabilitation Research and Development
Office of Technology Transfer (153D)
Veterans Administration
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Rehabilitation R&D Progress Reports is distributed to recipients on the mailing list for the Journal of Rehabilitation Research and Development. The mailing list is intended to cover all professionals in the rehabilitation field who are either actively involved in research, contemplate such involvement, or need to remain familiar with the direction and methods of current research and the clinical application of its results.

At present, the Journal and the progress report annual publication are distributed free of charge, both in the United States and in foreign countries. Additions will be made to the mailing list upon request to:

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Although it is not required for addition to the mailing list, it will be appreciated if those asking to be placed on the list furnish the following information for our reader-demographics databank: degree; area of particular professional specialization, license, or practice; and whether currently actively involved in a program of research.

In addition to mailings to individuals, copies in requested quantities go to VA Hospitals and Medical Centers, Clinics, and Regional Offices. Copies also go to certain Depository Libraries, and to libraries in schools and colleges, medical and research institutions, with or without government affiliation, in the United States and foreign countries.

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Rehabilitation R&D Progress Reports will also be on sale over the counter and by mail-order from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

Single-copy sales are offered for the benefit of those whose interest is limited to topics not covered regularly by the publication. We offer such individuals a free "Availability Announcement" of each issue. It includes a reproduction of the issue's Table of Contents along with an official Superintendent of Documents mail-order form.

A similar "Availability Announcement" will also be mailed for future issues of the Journal of Rehabilitation Research and Development, the new four-times-a-year scientific journal which also issues from this office. Those announcements will include a 10-year list of available back-issues (with prices) for the former Bulletin of Prosthetics Research and, of course, for Journal back-issues in the future.

Veterans Administration

Rehabilitation R&D Progress Reports 1983

Margaret J. Giannini, M.D.
Director

Rehabilitation Research and Development Service, Department of Medicine and Surgery, Veterans Administration.

Address correspondence to: Editor, Rehabilitation R&D Progress Reports, Office of Technology Transfer (153D), 252 Seventh Avenue, New York, N.Y. 10001.

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EDITORIAL

A Program for Improving Access to Rehabilitation R&D Progress

SELDON P. TODD, JR.

Editor
Rehabilitation R&D Progress Reports

Director
Office of Technology Transfer

Rehabilitation researchers need better access to the published literature in the multidisciplinary field of rehabilitation research and development in order to stimulate and direct scientific and technical progress.

The Veterans Administration, through its Office of Technology Transfer, has initiated a program that will improve access to the existing knowledge and continuing progress in this area. The program includes four new elements:

1. The Journal of Rehabilitation Research and Development—an interdisciplinary scientific and engineering quarterly, first published in July, 1983, which replaces the Bulletin of Prosthetics Research;
2. The Rehabilitation R&D Progress Reports—a comprehensive worldwide annual review of ongoing scientific research and engineering projects, of which this is the first issue;
3. The provision of indexes to relevant international scientific literature; and
4. A technically based periodical tailored specifically to the needs of practicing clinicians.

The Journal of Rehabilitation Research and Development is designed to provide a multidisciplinary approach to the publication of scientific and engineering papers. Traditionally, researchers have published in journals representing their specific fields. This practice has yielded a literature containing a substantial body of knowledge confined to journals generally read only by members of a particular discipline. Thus, it has become practically impossible for professionals to keep abreast of progress in the rehabilitation field as a whole. Cross-fertilization among the many basic disciplines has fallen far short of its potential. Clinical leaders do not have ready access to new techniques that could be adopted usefully and safely into practice.

The Journal of Rehabilitation Research and Development serves to fill this gap by presenting scientific papers of interest to rehabilitation professionals in a style of technical writing that is acceptable to dedicated specialists and understandable to leaders in the full range of the rehabilitation disciplines. Special emphasis is given to rehabilitation engineering developments, too few of which have previously appeared in well-circulated publications.

To assure quality, all articles are refereed by appropriate members of the Journal's Editorial Board and selected ad hoc reviewers. We are committed to offer our contributors the advantages of publication in a high-quality refereed scientific/engineering journal which reaches the full rehabilitation community. Thus, the Journal is widely disseminated within the United States and in foreign countries. The Journal is distributed upon request and, in most cases, without charge. Authors are to receive a generous supply of free reprints to further facilitate dissemination.

The Rehabilitation R&D Progress Reports, beginning with this issue, present an annual summary of ongoing work. This information is intended to facilitate communication in advance of project completion and publication of final results. The progress reports also offer a state-of-the-art perspective of activities in the field of rehabilitation research and development. This can be most useful to those with policy planning responsibilities, as well as those whose activities and opportunities may be affected by the policies and plans.

The purpose of the Rehabilitation R&D Progress Reports require different standards of content from those applied to articles in the Journal of Rehabilitation Research and Development. The progress reports identify the researcher, organizational affiliation, and sponsor in a way that invites readers to solicit more information directly from the investigators. Project descriptions give substantive but brief summaries of goals, progress, and future plans. Detailed information on experimental design and research procedure is not included in the progress reports; such material is appropriate for scientific articles.

Preliminary results of a project may be included in a progress report, but they are not intended to convey "new scientific information." Scientific findings, to be accepted as valid additions to the literature, must allow for replication through full reporting of experimental design, data reporting, data analysis, and interpretation. Such an in-depth presentation is not possible nor desired in the progress reports. The reports describe "working hypotheses" and identify ongoing commitments of scientists and engineers involved in the pursuit and testing of those hypotheses. Prejudgment of the outcome of preliminary results would be inconsistent with the purpose and scope of the progress reports. Moreover, it would ignore the fact that many valuable scientific discoveries occur when final experimental data turn up unexpected or surprising results.

Through the third element of the program, the Office of Technology Transfer is committed to the goal of making available comprehensive searches and access to indexes of relevant scientific and engineering literature from worldwide sources. Under development now are (i) descriptive guides for effective and economical scientific literature searches, including the use of computerized reference services and (ii) annotated bibliographic indexes in selected topical areas. In the long term, desktop computer-terminal selective searches of the full body of world rehabilitation literature could be the most effective method of attaining this goal.

The potential value of "unlocking" the foreign literature is an exciting part of our program. This issue of the Rehabilitation R&D Progress Reports implements our goal of providing the English language reader access to rehabilitation literature from other countries. Systematic dissemination of existing indexes of foreign literature, and regular publication in the Journal of Rehabilitation Research and Development of foreign articles not otherwise available in English translation, are also future goals.

Developing a technically based periodical tailored specifically to the needs of practicing clinicians is in the conceptual phase and represents the fourth element in our program to disseminate research information. It will be designed in coordination with professional organizations, in order to build upon and be supportive of ongoing efforts.

The VA Office of Technology Transfer is committed to improving access to the interdisciplinary literature in the field of rehabilitation research and development. The program outlined here is ambitious and to achieve it will take time, ingenuity, resources, and the full support of the rehabilitation community ■

Prosthetics/Amputation R&D

In this section, under the broad heading of Prosthetics/Amputation R&D, reports in the following general area will be found: **Comprehensive Amputation Management; Lower Limb Prosthetics; Upper Limb Prosthetics; Orthotics; Hip and Knee Joint Replacements; Lower Limb — General,** including **Gait Analysis** and **Miscellaneous; Upper Limb — General; Maxillofacial Prosthetics.**

COMPREHENSIVE AMPUTATION MANAGEMENT

VAMC TUCSON

COMPREHENSIVE MANAGEMENT OF UPPER AND LOWER EXTREMITY AMPUTATION

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The six main objectives of our Amputation Rehabilitation Program are (i) amputation level determination, (ii) development of temporary prostheses, (iii) immediate postsurgical fitting after upper extremity amputation, (iv) definition of application of upper extremity prosthetic components, (v) elective amputation for neurologic dysfunction; and (vi) Regional Amputation and Training Center.

Amputation Level Determination — Xenon^{133} skin clearance techniques still continue to be the most reliable test for amputation level determination. The validity of this technique has recenly been documented by the Surgery/Radiology Group at the University of Cincinnati who have not only confirmed the value of Xenon^{133} for amputation level selection, but also reaffirmed our previously published level of 2.6 ml/100 g tissue/min blood flow as the baseline which is adequate to ensure amputation healing. During the past year, we have analyzed Xenon^{133} clearance techniques as compared to the laser doppler and skin fluorescence. Although skin fluorescence does have some predictive value, there is not a sharp demarcation such as one sees with Xenon^{133}. Our preliminary laser doppler tests similarly suggest that there is not a fine discriminative point for the laser doppler. During the upcoming year, we plan to expand our laser doppler analysis and also compare Xenon clearance techniques with tissue oxygen skin tension.

Development of Temporary Prostheses — During the last 2 years we have developed and finalized techniques which utilize lightweight casting materials for the design and development of lightweight, cool, durable lower-limb temporary prostheses.

Immediate Fit After Upper-Limb Amputation — Preliminary data on immediate fit after upper-limb amputation has been verified by our subsequent patient population. More importantly, data from the Tucson VA Medical Center and from the Atlanta VA Medical Center (Emory University) was analyzed by both principal investigators (James Malone & Lamar Fleming) and similar data were found.

Definition of Application of Upper Limb Prosthetic Components — Our preliminary data would suggest that there is not a cost benefit to external powered prosthetic components and, in fact (as noted above) our general approach is to fit conventional components first and only after a patient has proved to be successfully rehabilitated will we then commit ourselves to powered components. This is not to imply that there is not a role for externally powered upper-limb components for the high or multilevel amputee. However, for the unilateral amputee, externally powered components have, perhaps, only a marginal value as compared to conventional components.

Elective Amputation for Neurologic Dysfunction — During the past year we have done two more amputations on patients with brachial plexus injuries. Our surgical approach involves shoulder fusion, elective amputation, and rapid fitting of upper-limb components. These patients have gone back to work, and we are continuing to be extremely impressed with the rehabilitation potential for upper-limb amputation in patients with non-recoverable neurologic impairment of the upper limb.

Regional Amputation and Training Center — We have added an Occupational Therapist/Program Coordinator to our program during the last year. We

are beginning to advertise indirectly for residents, students, and faculty who are interested in spending time in a dedicated Amputation Program in order to improve their diagnostic, surgical, and rehabilitative skills. Clearly, the rehabilitation results from Centers interested in amputation surgery continue to surpass the results from Centers wherein there is not a dedicated, interested team available ■

LOWER LIMB PROSTHETICS

VAMC SAN FRANCISCO

DEVELOPMENT, TESTING, AND EVALUATION OF NEW PROSTHETIC DEVICES

David J. Effeney, M.B., B.S., FRACS; Harry B. Skinner, M.D., Ph. D., FACS; Mark A. Abrahamson, B.A.; Leigh A. Wilson, C.P.; and **Ruth Roberts, R.P.T.**
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Survey of Problems & Needs — The first of these was a survey of 179 veteran lower-limb amputees from two Veterans Administration medical centers, in order to determine their prosthetic problems and needs. Individual prosthetic evaluations of 54 respondents by the research team defined more precisely the status of their prosthetic care.

The most striking finding from this study was the high incidence of residual limb discomfort. Fifty-four percent of both traumatic and dysvascular amputees complained of moderate-to-severe discomfort.About one half of the respondents noted difficulty in obtaining a comfortable socket fit. Among the 54 amputees evaluated individually, evidence of improper socket fit was found in 59 percent of the below-knee and 78 percent of the above-knee prostheses. Most of these problems were related to improper socket construction initially. The remainder were due to amputee-related factors such as changes in the size of the residual limb or deterioration of the socket and liner due to wear. Mechanical skin irritation or breakdown was found in 41 percent of the below-knee and 22 percent of the above-knee residual limbs. Deficiencies in prosthetic suspension, alignment, and foot function were common, and were often associated with compensatory gait deviations.

Excessive stiffness in the heel cushions of SACH feet was a frequent finding and this is being further evaluated in our on-going studies.

It is suggested that, in order to reduce the incidence of residual limb complaints in the veteran amputee population, the quality of the prosthetic care that is being provided needs improvement. Greater emphasis should be placed on earlier identification and correction of problems of prosthetic wear and maintenance — by both the amputee and outpatient personnel.

Clinical Study of UCBL Knee Linkage — The second of these studies was a clinical study of the UCBL 4-Bar polycentric prosthetic knee linkage. The mean follow-up period was 12.3 months. Very positive subjective responses were reported by 75 percent of the amputees, and more than one third stated that the device was superior to any that they had used previously.

Studies in Progress — Design of the Moveable Ankle Cushion Heel (MACH) foot has progressed to the modeling phase. A study of the properties of available foamed polymers, to optimize energy absorption stability and wear in such an application, has been started. Also included in this study is an evaluation of the static loadbearing properties of commercially available SACH feet.

We have concluded that there is no static difference in response between some "regular" and "medium" heels, and are planning to study the dynamic response in future studies.

In response to problems encountered with air leaks in the air cushion socket, we have developed a construction technique for the air cushion socket which improves the airtight seal. This socket, when properly fabricated, is highly successful for below-knee amputees with problem stumps, but the success is dependent on determination of the proper volume of enclosed air space for any patient and the major criticism has been air leakage.

The root of the problem lies with the interface between the elastic sleeve and the plastic socket. Even under the best of conditions there is a minor air leakage, due to the fact that there is no chemical bonding between the Dow Corning 3110 elastomer and the polyester resin at the proximal border of the elastic sleeve. The air leakage becomes worse with constant use of the socket, because the elastomer/polyester resin interface begins to break down or erode.

Several changes in the fabrication technique were devised as a solution to this problem. The first con-

sists of the lamination of a thin polyester resin shell (Banlon and fiberglass) which encapsulates the proximal portion of the plaster model to point 3/8 of an inch distal to the level of the tibial tubercle. The elastic sleeve is now laminated over the model to a level 3/8 of an inch proximal to the distal edge of the polyester shell. The lamination procedure for the elastic sleeve has also been changed. A 1/16-inch-diameter nylon cord loop is placed over the outer layer of the Banlon at the level of the tibial tubercle, prior to pulling on the outer PVA bag. The nylon cord has a dual purpose; it serves as a collection point for the R.T.V. rubber (thus forming a slight bulge) and helps prevent the R.T.V. from bleeding into the fabric beyond the desired point of lamination. The fabrication procedure now continues as previously outlined by Wilson et al. The R.T.V. bulge at the proximal border of the elastic sleeve is now sandwiched between two polyester resin laminates (the outer socket and the inner proximal shell), which forms an airtight barrier ■

NIHR REC

PROSTHETIC INTRAMEDULLARY PYLON: LONG-TERM IMPLANTATION STUDIES

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Objective: The goals of this research project were to investigate selected materials, optimize mechanical design, and develop surgical techniques for long-term endoskeletal attachment of prosthetic limbs.
Summary: The final design represents a compromise between considerations for (i) minimizing bone stresses during loading, (ii) providing minimal disruption of the endosteum, and (iii) machining limitations/expense. The design results in stress distribution through the pylon below ultimate failure strengths for cortical and woven bone up to load levels of 7000 pounds and 600 pounds, respectively, in axial and torque loading.

Radiograph, gross photographic, and histological evidence have been positive in terms of analyzing tissue reaction to the implant. Light and scanning electron microscopy have confirmed that normally ossified tissue is forming in areas that were removed during tapping of the bone. Although there is a thin fibrous layer adjacent to some portions of the implant, in general the tissues appear healthy and richly vascularized.

Overall, the results obtained in these implantation studies of the carbon-coated titanium pylon have been extremely encouraging. Stable bone implants have persisted for periods up to 5 years ■

NSF

MICROCOMPUTER-CONTROLLED, INDIVIDUALIZED MULTIMODE PROSTHESES FOR LOWER-EXTREMITY AMPUTEES

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The research effort involved in this program is a continuation of an effort to improve amputee mobility through development of control schemes and interactive simulation systems. As a spin-off from use of the interactive simulators, electrically modulated knee-torque controllers have been shown to be viable with regard to size, weight, and power consumption. The research contributes to a new generation of artificial legs, and also to improved robotic manipulators. Through microcomputer control, the prosthetic devices are expected to have a versatility and adaptability far beyond previously existing prostheses.

The program aims to elucidate the basic control algorithms and also the hardward configuration required for laboratory experimentation. This is the first year of a 3-year continuing grant ■

VAMC SEATTLE

PHYSIOLOGIC SUSPENSION FACTORS IN BELOW-KNEE AMPUTEES EVALUATED

Frederick G. Lippert III, M.D.; Ernest M. Burgess, M.D.; and **Thomas W. Starr, BSME.***
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This project has shown that suspension by physiologic mechanisms alone is achievable. The goals now are to develop a protocol to determine the physiologic suspension potential of any amputee by clinically measuring stump and socket factors contributing to suspension. Prosthetic modifications and training techniques are also proposed to take maximum advantage of this potential.
Methods — We have accumulated a data base of suspension parameters and suspension function on 60 definitve and 28 research prostheses. Co-variance

analysis has been applied to the data. Subjective input with regard to suspension function has been gathered through the use of a questionnaire. An isometric training protocol has been used to improve physiologic suspension.

Five prostheses were made incorporating physiologic suspension factors.

Definition and description of data base parameters can be found in our last report. Co-variance analysis did not identify any of these as clear predictors of suspension performance. The questionnaire has also been published.

Subjects were issued ankle weights for isometric training. The training protocol consists of lifting the prosthesis/weight by physiologic components alone, holding it up for 10 seconds, then resting.This is repeated 10 times, twice per day. Subjects are evaluated serially during training.

Definitive physiologically suspending prostheses are produced by a standard two-stage casting technique with the following modifications: muscle bulges are marked before casting; residual limb musculature is contracted for the first stage and relaxed during the second; muscle bulges are accentuated to predetermined dimensions during the model rectification process, with care to avoid bony areas.

A clear thermovac socket is attached with Otto Bock endoskeletal components to a foot provided by the amputee.

Comprehensive evaluation of limb fit and function is carried out at initial fitting. Residual limb and socket factors are noted. Function is evaluated by having the subject lift calibrated weights (Fig. 1). Gait analysis, alignment, and dynamic evaluation of the physiologic suspension are carried out concurrently. The subject must be able to ambulate comfortably without distal gapping (Fig. 2) and be able to apply a tensile force of at least 25 Newtons, physiologically, to the prosthesis. Ancillary suspension is added at this time if necessary. The amount of weight the subject can lift serves as a baseline by which to gauge progress. (Lifting is accomplished with the knee bent to eliminate the contribution of a taut patellar tendon and hamstrings to overall suspension.)

FIGURE 1
Calibrated weights aid in the evaluation of the effectiveness of physiologic suspension.

FIGURE 2
The subject must be able to ambulate comfortably without distal gapping.

Impact — Of the 60 subjects measured in unmodified prostheses, 6 produced better-than-average suspension by physiologic components alone. Isometric training within the socket improved suspension in 9 of 10 selected subjects. Physiologic suspension can also be improved by the addition of pads proximal to muscle bulges within the socket.

Unexpectedly, 50 percent of subjects ejected their unmodified definitive prostheses by contraction of the residual limb musculature; this occurs if the contracting muscle mass presses against the socket distally. Our modified sockets enhance physiologic suspension even where the contraction potential of the musculature is small.

Prosthetic modifications which take into consideration physiologic suspension factors, as well as training within the prosthetic socket, improve amputee function ■

*Dr. Lippert is Chief, Orthopaedics Section, VA Hospital and Medical Center, Seattle, Washington. Dr. Burgess is Director, VA Medical Center Amputation Service, and Principal Investigator, Prosthetics Research Center, at Seattle, Washington; Mr. Starr is Research Biomedical Engineer and Prosthetist, VA Hospital and Medical Center, Seattle.

VA CONTRACT

DEVELOPMENT AND IMPROVEMENT OF RUNNING SKILL IN UNILATERAL BELOW-KNEE AMPUTEES

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This 2-year project is concerned with procedures for developing and improving the running gait of unilateral below-knee amputees. The ability to run or jog at least short distances permits the ambulatory amputee to participate in games and sports, with potential associated benefits of weight control, cardiovascular conditioning, stress management, and the enhancement of self-esteem.

General Protocol — The protocol involves between 15 and 20 amputees and consists of three major phases: a comprehensive preliminary evaluation of functional status, social-psychological variables, and running skills of each participant; a formal program to improve running performance of these individuals; and a final assessment of success achieved. Continued efforts are also being made to provide additional information on the biomechanics of amputee running.

A questionnaire has been developed to assess possible mediators of self-esteem change and social psychological factors that may affect the extent to which subjects successfully complete the running-skill program. Among the variables assessed by this questionnaire are subjects' program goals, performance expectancies, perceptions of current ability, current physical activities, and certain aspects of relationships with family and peers.

Biomechanical Analysis of Running Skill — Subjects are filmed at approximately 100 fps as they run across a .6 m x .9 m force platform connected on-line to a laboratory computer which samples the ground reaction force output at 1000 Hz. Between 10 and 20 trials at varying speeds are recorded. Approximately half of the trials represent prosthetic foot strikes on the force platform. Ground reaction force components and center-of-pressure paths are output in digital and graphic formats. Films are analyzed both qualitatively and quantitatively. At the first level of quantitative analysis, temporal and length characteristics of the stride are noted. At the second and more complex level, linear and angular position-, velocity-, and acceleration-time histories are determined, and resultant torques and forces at the ankle, and knee, and hip joints calculated.

Maximum ground reaction forces recorded on the prosthesis, while they are between two and three times body weight, are not significantly different from those on the intact foot or for nonamputee runners.

The most common anomaly in the running patterns of those below-knee amputees who do not run on a regular basis continues to be the maintenance of an excessively straight residual knee during the majority of stance on the artificial limb.

In summary, findings from this study regarding physical performance characteristics of amputee running and psychological mediators of self-esteem change and performance success should have important implications for the physical rehabilitation of lower-limb amputees who want to return to a physically active lifestyle ■

UPPER LIMB PROSTHETICS

NUREP

MICHIGAN ARM

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This project has been a cooperative effort by NUREP and the Area Child Amputee Program, Grand Rapids, Michigan. The objective of this project is to design, develop, and clinically evaluate electrically powered prostheses for a child who has congenital bilateral amputations at shoulder level.

The first phase of this project, which is completed, was to develop the prosthesis which has powered elbow flexion coupled with wrist motion to maintain the terminal device in a fixed attitude in relation to a horizontal surface (table) at all elbow positions. The terminal device is the commercially available Michigan Hook, and both hook and elbow are controlled by switches. To conserve battery energy, a timing circuit will shut off the motors if they are in a stalled condition for more than 5 seconds. The humeral section length can be adjusted to compensate for growth. Three prototypes have been fabricated and are now being fitted to children for clinical evaluation.

The second phase of this project is to apply the principles of extended physiological proprioception to the control of the prosthesis ■

VA-NUPRL

BELOW-ELBOW PROSTHETIC SYSTEM

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The objective of this project is to develop a below-elbow prosthetic system with hook/hand interchangeability and easily removable modular components. The components consist of the terminal device, battery, electronics package, electrode package, and wrist connector.

A rigid cover is being fabricated for the synergetic hook to protect the mechanism from contaminants and mechanical damage. The cover is to be "technological" in appearance rather than cosmetic. The rationale is that the hook is a technological device and not a replica of a hand.

The wrist connector, which combines the electrical connection with the mechanical connection between the terminal device and the forearm, has been redesigned. It fits within the structure of commercially available prosthetic wrists and the terminal device mounting stud. More importantly, this arrangement does not increase the length of the wrist or the terminal device. The three-conductor electrical connector used in this assembly is commercially available. The terminal device can be rotated 1¼ turns and yet maintain electrical contact.

The electrode package is the "Myotrode" described elsewhere in this publication under the NUREP Progress Report. The development of this electrode/amplifier assembly has been completed and a laminating technique to mount the assembly in the prosthesis is being investigated ■

NUREP

MYOPROCESSOR

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The objective of this project is to develop a single-site signal processor with a single output. This permits control of one motor in one direction. There are at present, two devices commercially available to which this controller can be applied: the Michigan Hook, and the Hosmer Dorrance Prosthetic Assist (PA) which will operate any voluntary opening hook.

When used with the Michigan Hook, a timer circuit is added to turn the motor off and conserve energy after approximately 3 seconds of stall. Powered by a nine-volt rechargeable battery, the hook will give about 3 days usage between charges. The quiescent current is 46 micro amperes at nine volts.

When used with the PA system, a timer circuit is not required because of a cut-off circuit built into the device. In this system the quiescent current is 29 microamperes at 6.25 volts.

The myoprocessor will operate at from 1.5 volts to 18.0 volts. This wide operating range ensures that the electronics will remain stable and operational until the battery voltage will no longer open the hook ■

ORTHOTICS

LIBERTY MUTUAL, NIHR, SWEDEN

MYOELECTRIC PROSTHESES FOR CHILDREN

Carlo J. De Luca, Ph. D., and **Joseph Carideo, Prosthetist**

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and
Liberty Mutual Research Center
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During the past year, we have constructed and fitted a myoelectrically controlled mechanical hand for a 3-year-old girl. Mara is a congenital amputee. The hand was obtained from Systemteknik AB of Sweden.

This development was noteworthy for three reasons. First, few such prostheses have been fitted on children so young. Second, Mara had a petite physical stature (weight = 11 kg, height = 86 cm). Third, her forearm stump was exceptionally short, and only approximately 7 cm² of flexor and extensor muscle tissue in total was present. The technical complications were satisfactorily resolved. She is reportedly actively using the prosthesis.

The fitting of a similar prosthetic hand to a 7-year-old child is underway, and we are contemplating the design of a myoelectric prosthesis for a 13-year-old ■

NUREP

MYOTRODE

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This is an active electrode package that places the amplifier at the electrode site to eliminate electrical interference problems and give greater flexibility in placing the electronics in different prostheses. The electrode buttons are removable from the package to allow a choice of button heights to maintain optimum skin contact. This also allows the use of other electrode material such as conductive rubber for use with other systems such as environmental controllers or communication aids.

Several Myotrodes have been built using Surface Mounted Device (SMD) techniques. These will be utilized in the modular Below Elbow Prosthetic System discussed elsewhere in this publication under the NUPRL Progress Report ■

VAMC ROXBURY

A MOTION-GUIDING, LOAD-BEARING, EXTERNAL FRAME FOR THE KNEE

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Internal joints must allow the ligaments to act at correct lengths, while external joints must guide motion and prevent unwanted ligament tensions. Thus key questions for implant design are: what is the geometry of the natural joint surfaces and how much sliding occurs in flexion-extension? For external orthoses and hinge distractors, extra questions are: to what boney landmarks can the joints be lined up, what external points should be guided, and what is their motion?

Materials and Methods — Twenty-two distal femurs were aligned to defined axes, embedded, and cut into 16 equal sagittal slices. The 17 sections of each bone were digitized into a computer. The points articulating from 15–105 degrees flexion of sections 3-6 (lateral) and 12-15 (medial) were determined. The best-fit sphere was determined by iterations of x,y,z of the center and radius r. The criterion was the minimum sum of the absolute distances of the points to the sphere. On 14 other knees, the sagittal radii of the posterior condyles were measured, and in frontal profiles 0,30,60,90 degrees of flexion. Radius gauges spaced by 1 mm, enclosing a 90 degree arc, were used. The m-1 spacing of the condyles was also measured.

It was essential that the motion measurement be applicable to normal subjects as well as specimens. The 14 fresh intact knees were mounted in a rig and sagittal X-rays taken at from 0 to 120 degrees of flexion under quadriceps tension. Key reference points were digitized, with 6 points on the lat. and med. femoral condyle peripheries. The center of the best-fit circular arc was computed. A similar analysis was carried out from movie X-rays of 8 normal males ascending a steep step.

The two centers of the medial and lateral 'spheres' defined the femoral x-axis; the y-axis was vertical at 0 degrees of flexion, and the z-axis was anterior at 0 degrees of flexion. Using an Eulerian system with minor approxns. int-ext rotation, varus-valgus a-p and vertical translations were computed as a function of flexion. Accuracy analysis showed the centers of the circular arcs were to ± 1 mm for specimens and ± 1.5 mm for volunteers.

Results — The geometry was standardized to an m-1 femoral dimension of 80 mm, and an a-p tibial dimension of 50 mm. The points on the lateral and medial condyles deviated from the best fit sphere by only 0.53 ± .20 and 0.63 ± .22 mm respectively.

Thus, a spherical surface of 20-mm radius for the posterior femoral condlyes of standard sized knee was a close representation.

The motion of the cadaveric knees from 0-120 degrees showed a posterior displacement of the femoral origin of 7.4 mm: the lateral sphere center moved back 17.0 mm but the medial sphere center moved forwards 4.5 mm to mid-range, than back to a net 2.2 mm. The transverse femoral axis rotated 20.2 degrees on average (equiv. to an internal tibial rotation). The origin moved downwards net 2 mm from 0-120 degrees of flexion, most occurring from 0-30 degrees of flexion. From 0-45 degrees of flexion there was a 4.2-degree varus movement of the femoral axis, thereafter decreasing to 2.2 degrees.

The motion in the volunteers was statistically indistinguishable ($p<.01$) from that of the specimens. The lateral sphere center moved back 14.1 mm and the medial forwards net .3 mm. Transverse rotation was 16.9 degrees.

Applications — A 3-D computergraphics display program was written and a condylar knee design was input to show the internal-external rotation contact geometry. An external linkage was designed, which controlled the transverse femoral axis on the medial and lateral sides independently, using a cam mechanism. These will be shown.

Conclusions:

1. The posterior femoral condyles can be accurately modelled as spherical, and the centers used as reference points for motion studies.
2. Internal joints should allow for translation and rotation patterns, as well as additional 'laxity' in each position.
3. External linkages can use the spheres for location and can guide motion by controlling the projection of the transverse femoral axis ■

NUREP

DESIGN & EVALUATION OF A KNEE ORTHOSIS

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The primary objective of this project is to improve orthotic treatment in the rehabilitation of the knee joint.

The improved orthotic joints are semiconstrained and anatomically shaped, and were shown to have minimized the pistoning constraint normally associated with orthotic joints. Stability is added to the joints by the sequential tightening of a set of inextensible Dacron straps ("ligament" straps) crossing the joint, simulating the knee ligaments. Anterior cruciate, posterior cruciate, and collateral ligament strap configurations were designed. Since the orthotic joints minimize the pistoning constraint, significant improvements to the orthotic interface could be realized, increasing its suspension to the lower limb. Interface improvements include the use of a medial femoral suspension pad and a proximal tibial suspension member, each with its associated strapping arrangement.

During this reporting period, several refinements to the above basic design were completed, including the incorporation of different types of plastics into the interface (depending upon the clinical application of the orthosis), the redesigning of potential structurally-weak areas in the orthosis (attachment methods for ligament straps, ligament attachment plate, etc.), and the use of a thermoplastic thermobonding technique to attach joint sidebars to the interface components.

For the purpose of guiding further design improvements and modifications, a general series of clinical trials was initiated. A formal clinical evaluation has now been initiated. Approximately 70 people have been fitted with orthosis. Further design modifications continue to be made ■

VAMC SAN FRANCISCO

THERAPEUTIC MOLDED SHOE PROJECT

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Introduction — It has long been recognized that molded shoes have a definite place in the treatment of static foot deformities, trophic lesions, and ulcerations in diabetics and others with compromised circulation in the lower extremities. This is accomplished, essentially, by redistributing pressure on the plantar aspect of the foot, from concentrated localized areas such as beneath a metatarsal head or other bony prominence, to a much larger surface — with resultant decrease in pressure over the local pressure point.

Two major problems associated with molded shoes are high cost and lengthy delivery time. This project directs itself to these two problem areas.

The VA provides thousands of pairs of molded and other types of shoes at a cost ranging from $150 to $350 a pair, and with a delivery time of 4-12 weeks ■

HIP AND KNEE JOINT REPLACEMENTS

VAMC WOOD

STUDIES OF NORMAL AND ABNORMAL MOTION

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During the period of January 1, 1982, to June 30, 1983, the Kinesiology Research Laboratory continued its investigations into the nature, rate, and extent of change in functional performance in patients with total joint replacements.

Total Hip Approach Study — The purpose of one study was to identify the functional advantages or disadvantages between the anterolateral and posterior approaches to total hip arthroplasty. Prosthetic position, hip muscle strength, and hip joint mobility were measured after Muller total hip arthroplasty without osteotomy in 52 patients operated through a posterior approach and 41 patients operated through an anterolateral approach.

When the posterior approach was used, the men and women had less prosthetic component anteversion and longer neck lengths, with resultant more lateral and distal placement of the greater trochanter than when the anterolateral approach was used. Groups operated through the posterior approach had more normal hip-abductor-muscle strength and more inward rotation of the affected side than groups operated through the anterolateral approach.

Groups with an anterolateral approach had more outward rotation on the affected side than groups with the posterior approach.

These differences in function were related to the surgical approach rather than to differences in prosthetic component position. An understanding of these observations should be useful for selection of the surgical approach for the patient on an individual basis.

Knee Joint Replacement Study — A second study measured the preoperative and postoperative functional performance of a group of patients with an unconstrained type of knee joint replacement. The purpose was to provde an objective evaluation of functional change as a result of surgery ■

NUREP

STRUCTURAL ANALYSIS OF TOTAL JOINT REPLACEMENTS

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Surface Replacement Hip Arthroplasty — The objective of this project is to use a three-dimensional finite element analysis to better understand the causes of surface hip arthroplasty failures, and to develop improved designs. During this reporting period, a three-dimensional finite element model of the proximal femur and surface hip component was generated, accurately modelling the geometry of the actual system. Two cases have been run; the natural femur and the femur with implant. Data post-processing has been completed. The data has not been analyzed to date; however, it appears to qualitatively agree with other investigators.

Finite Element Analysis of Proximal Femur and Femoral Component of a Total Hip Replacement, with Inclusion of a Fibrous Tissue Layer at the Bone/Cement Interface The objective of this project is to determine the consequence of the fibrous tissue layer on the stress distribution of the total hip implant system. A realistic element modelling the fluid-filled interface tissue has not been developed to date, since the major effort has been directed into the experimental measurement of the fluid flow properties of the interface tissue. However, two extreme finite element (three-dimensional) cases have been run, modelling a total hip with a perfect interface bond along the distal one half of the stem, and with no interface bond at all (i.e., no cement between the metal and bone). Eventual inclusion of the fibrous tissue element in the model will yield results somewhere in between these two extreme cases. The bond/no bond comparision results showed increased cancellous bone stresses at the distal end of the bonded region, but otherwise, little difference occurred between the two analysis cases.

Stress Analysis of Total Hip Prostheses By Finite Element Methods The objective of this subproject was to use previously generated three-dimensional finite element data to address specific questions regarding the analysis of total hips, such as the effect of neck length, magnitude of adductor muscle force relative to head contact force, and anterior-posterior directed head force versus inferior directed head force ■

NUREP

PROSPECTIVE CLINICAL STUDY OF THE KINEMATIC KNEE DESIGN

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This is an ongoing project to follow Kinematic Knee patients in an attempt to identify quantitative relationships between clinical data and the eventual outcome of Kinematic Knee replacements, and to evaluate the effectiveness of this particular prosthesis in eliminating pain and restoring and rehabilitating severely disabled individuals to normal active lives.

Data was collected from hospital and operating surgeon files. Data included component type, patient history, posterior cruciate retaining, anterior cruciate retaining, and stabilizer type, as well as physical, surgical, and X-ray findings. Investigation of developing radiographic radiolucent lines between implants and bone has also been implemented, along with a conversion program which converts our data into the Knee Evaluation scale of the Hospital for Special Surgery.

To date, 92 patient cases have been included in the study. Of these, initial statistical analysis has been performed in 82 cases. These cases have been followed-up in an ongoing fashion in attempt to achieve a 6 month, 1-year, and 2-year followup at minimum. However, the number of cases not yet possessing a 2-year followup is large. For that reason, significant statistical analysis has not yet been performed. Preliminary demographic and statistical analyses have been performed ■

NIH/VAMC CLEVELAND

IN VIVO LOADING ON TOTAL KNEE JOINT REPLACEMENTS*

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This project is to determine in-vivo loading data in total knee joint replacements. The new joint replacements will have, incorporated within the body of the tibial component, the required circuitry to telemeter seven channels of loading data, allowing for the determination of the three forces and the three moments on the tibial component. As shown in Figure 1, the project requires two basic systems; the implanted mechanical and electronic portion, and the external portion which handles telemetry reception, demodulation and digitizing. This progress report will detail the work accomplished and the work proposed on each of these requisite sections.

Current Status — The hybrid microcircuit for the implantable transmitters and subcarrier oscillators is being fabricated in a collaborative effort with the General Electric Co. We have also received batteries from Battery Engineering Inc. (manufacturer of Medtronic's pacemaker batteries) which were developed to our specifications.

The problem of keeping the electronics hermetically isolated, and all other materials biocompatible, has been solved through a cooperative effort with the Inco Corp., BLH Electronics, and the Glasseal Corp. As a result of this collaboration, it has been decided to use platinum as the conductor for all wiring external to the actual electronics package. Glasseal Corp. is engineering a 16-pin hermetic header having platinum pins in a titanium disk, for use as a signal path between the load-cell strain gages and the encapsulated electronics in the stem. BLH has agrees to construct special strain gages with insulated platinum leads for use on the load cells; they are also supplying the special tip needed to allow us to spot-weld all interconnections to these gages. We are currently supplying BLH with the insulated platinum wire to fabricate these gages.

We have also addressed to the problem of switch failure, previously encountered in this project. Axialite Engineering is fabricating for us a new switch with rhodium plating on the contact area of the reeds. This is intended to preclude any possibility of the previously noted gold degradation which could affect switch reliability.

In the area of mechanical development, we have contracted with a firm to manufacture our housing and tray assemblies from stock supplied by us, using EDM machining techniques. Because of that technique we have made minor revisions to noncritical areas of the design of these components, at the company's request. The minor revisions took the form of relaxation of some tolerances where allowable, changes in the dimension and location of specific radii and fillets, and surface-finish modifications ■

*Dr. Brown reports that this project now has a funding designation of NIH #AM-21559-05 and all funding is currently being administered by the National Institutes of Health. However, he notes, "a significant portion of the funds are derived from the original VA sources." Readers may recall seeing the project listed in the Bulletin of Prosthetics Research, Fall 1981, under both VA and NIH auspices. For previous years the reports will be found in the BPR's VA Progress Reports pages.

NIH MUSCULOSKELETAL

IN VIVO LOADING ON TOTAL KNEE JOINTS

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The purpose of this project is to determine the in vivo loading data from total knee joint replacements. These new joint replacements will have incorporated within the body of the tibial components the required telemetry circuitry to telemeter seven channels of loading from the device. These channels will be used to record the loads on the device, allowing for the determination of the three forces and the three moments on the tibial components ■

NIH MUSCULOSKELETAL

BIOMECHANICS OF HIP AND KNEE

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The specific aims of this research are:

1. To investigate the effects of incorporating fiber length, fiber direction, and fiber type into the existing muscle model.
2. To investigate the effects of differing cost functions on muscle force predictions and to study the appropriateness of using differing cost functions for differing activities in normal subjects and in subjects with selected abnormal conditions.
3. To investigate, in a comprehensive manner, the effects of varus, valgus, displacement, and rotational proximal femoral osteotomies on three-dimensional hip joint forces.

The first specific aim will be accomplished with cadaver dissection and with a sensitivity analysis in the existing muscle model. In that sensitivity study, fiber length, fiber direction, and fiber type will be altered over a reasonably physiologic range of variation to determine the effects on muscle forces.

The second specific aim will be carried out with a parametric computer study in which identical kinematic and kinetic input is subjected to the muscle force predictions using varying cost functions. The differences in muscle forces will then be compared.

The data of the third specific aim is already completely collected and will be analyzed and reported in the coming budget year ■

NIH MUSCULOSKELETAL

TOTAL SURGICAL REPLACEMENT OF THE HUMAN HIP JOINT

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This project is directed to the study of skeletal fixation using porous metallic composites. Specifically, the ion metal release, transport phenomenon, and related systemic effects in porous sintered powder composites of cast cobalt chrome (ASTM F-75), wrought cobalt nickel chromium molybdenum (ASTM F-562), and Ti6A14V (ASTM F-136) alloys will be studied. The related organometallic complexes will be isolated and their toxicity assessed using in vitro fibroblast cultures.

It is also intended to evaluate the tumor induction risk of porous sintered powder cobalt chrome composite (ASTM F-75) and wrought cobalt-nickel-chromium-molybdenum (ASTM F-562 also know as MP35N) in solid, powder, and porous form.

The possibility of bone growth enhancement into fiber titanium composites by the use of hydroxyapatites, tricalcium phosphate, fluorides, bone marrow contents, bone morphogenetic protein, and direct current electrical stimulation will be evaluated.

The effectiveness of three different titanium porous configurations will be compared: fiber titanium composite as a total or partial coating, and sintered titanium spheres as a method of fixation of a total hip prosthesis. The ability of bone to remodel and related effects of the material on the surrounding cortex will be evaluated.

An acetabular prosthesis of a hemispherical design will also be evaluated in terms of its potential for bone ingrowth as a means of fixation ■

NIH MUSCULOSKELETAL

MECHANICS OF THE HUMAN ACETABULUM

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This investigation will elucidate the structural behavior of the normal human acetabulum and examine the alterations in acetabular mechanics after total hip replacement, surface replacement, and femoral endoprosthesis hip arthroplasty. The project will involve direct mechanical testing of cadaver specimens and the generation of two-dimensional/three-dimensional finite element models for numerical stress analysis.

An in vitro mechanical testing program will employ multiple strain gage rosettes to determine the strains in the acetabular region of four normal hip joints during one-legged stance. After testing, the pelvis will be embedded in acrylic resin and sectioned. The global geometry will be determined. Each section will then be examined under reflected light microscopy, and quantitative morphometric measurements of bone areal fraction and trabecular orientation will be mapped out for each section. Two two-dimensional and three three-dimensional finite element models (FEMs) will be constructed. The bone of the acetabular region will be modeled as a heterogeneous material. Material properties will be assigned to elements according to the morphometric parameters. The results of the FEMs will be compared to the mechanical testing data, and the models will be refined in an iterative manner to ensure good correlation between the experimental and theoretical results.

The experimentally verified FEMs of the acetabulum will then be used to calculate the deformations and stresses after total hip arthroplasty. Several different surgical techniques and prosthetic components wil be evaluated. Important findings from FEM analysis of hip arthroplasty will then be experimentally verified with additional in vitro mechanical testing using strain rosettes ■

NIH MUSCULOSKELETAL

VASCULAR RESPONSE TO HIP REPLACEMENT

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The incidence of postoperative deep vein thrombosis in persons undergoing hip replacement surgery is around 50 percent and is a major complication of this surgery. There is currently no generally accepted method of prophylaxis despite much work on hemostatic components of thrombi. Thus, other mechanisms should be considered.

The applicants postulate that hip replacement surgery in dogs (and probably in people) initiates a series of events that culminate in indirect injury to and reduced blood flow in veins distant from the site. Suggested mechanisms for lesion formation in canine veins is based on observations in canine models studied by the applicants. It is suggested that human and canine veins respond similarly to hip replacement surgery, since they developed identical lesions in one model in which both were available. Others have found that venous blood flow in dogs and people have similar characteristics and respond similarly to some factors. Thigh veins on the operated side may also suffer direct injury from manipulations required during surgery.

It is the applicants' long-term objective to elucidate mechanisms responsible for venous damage and reduced blood flow. Because of the complexity of the surgical situation, a systems approach will be employed. A canine model of hip replacement surgery will be used. Veins will be examined and lesions studied by scanning electron microscopy, and the same veins will then be processed for study of architecture by light and transmission electron microscopy. Venous responsiveness will be monitored noninvasively by a modified ultrasound instrument. Blood flow will be studied by electromagnetic flow and Doppler ultrasound. Veins will be examined for direct injury by radiography and scanning electron microscopy. Major cardiovascular components will be monitored by appropriate methods, as will body temperature. It is important to note that four clinically relevant anesthetic techniques will be compared in these studies. The two noninvasive ultrasound techniques will be applied to patients undergoing hip replacement surgery to provide some basis for estimating similarity of response in human and canine veins as well as possibly providing clinically relevant information on the patients ■

VAMC GAINESVILLE

QUANTITATIVE ANALYSIS OF THE EFFECT OF TOTAL HIP ARTHROPLASTY ON STRESS AND STRAIN IN THE HUMAN PELVIS

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Phase 1 of this investigation served to provide the first prototype system to analyze the effects of acetabular preparation techniques on strain in the cadaver pelvis. Current goals include the evaluation of the changes in strength and stiffness of the bony pelvis-acetabular component following different implantation techniques, including:

1. No cortical reaming (inner and outer cortices intact) compared to reaming through the lateral cortex; leaving the inner cortex intact.
2. Different use of keying holes (none, three large, and multiple small).
3. Use of uniform mantle of cement between the bone and prosthetic acetabulum.

4. Different techniques for cement insertion (pressure injection, hand insertion).
5. Different component thicknesses (thin-wall surface replacement components, smaller-diameter, thicker-wall, conventional components), and
6. Different encasement methods (metal-encased polyethylene acetabular components, standard components without metal encasement).
7. Methods of supporting the acetabular component where a deficient medial wall may exist (including use of a protrusio ring and wire mesh reinforcement).

Quantitative biomechanical evaluation is planned of the following new prosthetic designs or techniques:

1. Graphite-fiber-reinforced polyethylene acetabular prostheses.
2. Non-plastic aluminum oxide uncemented components.
3. The use of pressure-injected low-viscosity cement in place of standard cements placed at "dough stage."
4. Newly suggested reinforcing techniques for the deficient acetabulum ■

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VAMC CLEVELAND

LATE LOOSENING IN TOTAL JOINT REPLACEMENTS IN THE LOWER EXTREMITIES

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The objective of this study is to document in-vivo motion of the cement/bone interface in total hip and total knee replacements. A Biplane Radiographic Technique is used to measure the distance between markers implanted in bone and implanted in cement at the time of surgery. Weightbearing and non-weightbearing X-rays are taken postoperatively before discharge, at 2 and 4 months, and every 6 months thereafter. The X-rays are analyzed by computer. The data from each patient visit is stored in, and can be retrieved from, the computer's data bank.

Patients continue to volunteer to take part in this research program, so that the participating patients' lengths of time in the study vary from 2 weeks to 5 years. Approximately ⅔ of all patients studied have shown some motion at the cement-bone interface at some time during our study. Such motion may or may not be associated with clinical symptoms.

The patient pool is approaching a size that determines the relationship between loosening and various patient characteristics (e.g. weight, age, and activity). Thus, during the last 18 months, along with our continued patient monitoring we have been modifying our computer hardware and software to permit such statistical studies ■

NUREP

EVALUATION AND DEVELOPMENT OF BIOMATERIALS USED IN TOTAL JOINT REPLACEMENTS

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This project area was addressed during the reporting period by two subprojects, as described below.

New Implant Materials: The most common metal alloy used in total joint replacement and internal fixation devices, 316L stainless steel, displays undesirable pitting and crevice corrosion, particularly in implant environments where ion concentration is high. The objective of this subproject is to find and evaluate viable substitutes for the 316L alloy, with superior corrosion resistance without sacrifice of mechanical properties.

Ferritic and duplex austenitic ferritic stainless steels are promising candidates, as they have demonstrated superior corrosion resistance in other fields. E-brite (a 26Cr-1Mo ferritic stainless steel) was compared with 316L stainless steel by potentiostatic and potentio-dynamic polarization, linear polarization, and cyclic polarization (ASTM-F4 Pitting and Crevice Corrosion Standard). The results of these tests show that the E-brite alloy does indeed possess superior corrosion resistance in an electrolyte of biological interest (without loss of structural mechanical properties).

Relative Polymeric Radiopacity: Polymers cannot be visualized within the body by X-rays. Hazard to

patient population may result from undetectable polymers, such as untoward mobility of polymeric bone cement used in total joint replacements. Radiopacity of bone cements is increased by adding inert heavy metal salts — which weaken the mechanical properties of the polymer. At present, there is no adequate method for evaluating the radiopacity of a polymer. The objective of this subproject is to develop a consistent methodology for evaluating polymer X-radiopacity in order to optimize control of variables (kilovoltage, milliamperage, film type, developing conditions, and exposure time), to get better visualization and minimize patient X-ray dosage. X-rays were taken of samples of aluminum and bone cements (low viscosity and regular) of varying thicknesses, with ranges of kilovoltages and milliampere seconds. X-ray film and processing variables were kept constant. Combinations and permutations of these variables on the X-ray films were analyzed by a photoelectric densitometer. It was found that the radiopacity changes dramatically with the test variables. Further data will have to be taken, including the effects of film type and processing, and an attempt will be made to develop empirical solutions to fit the generated data ■

NUREP

INVESTIGATION OF THE BONE/BONE CEMENT/IMPLANT INTERFACE FORMED BY TOTAL JOINT REPLACEMENT

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The objective of this project was to identify the causes of late loosening of prosthetic components by examining three aspects of the interface system.

1. An investigation was made of the major factors affecting the mechanics of bone-cement interface failure. A series of control and experimental tensile tests on bone/cement interfaces was performed, varying cement application pressures, duration of pressure application, and bone surface condition while measuring bone strength, failure load, and cement penetration depth. Statistical analyses of these variables were then carried out.

The penetration and failure load results were dominated by the application pressure. However, the quality of the fixation is limited by the bone properties. Low-strength, porous bone supports low failure loads due to poor bone quality. Strong, dense bone limits fixation quality by its resistance to adequate cement penetration.

2. A study was made of mechanical and histological properties of the soft interface tissue commonly found at the bone-cement interface system and how load is transferred across this interface. The procedure followed was to implant metal tibial components of a plate-post design into dogs, remove the implant after 2 months and measure the surface permeability of the post cavity (plus that of freshly cut cancellous bone) and then use this measured permeability in a mathematical implant simulation to predict the relative load carried by the fluid and tissue matrix.

It was found that the permeability of the implant cavity is much less than that of freshly drilled cancellous bone. The body has responded to close off the implant cavity to fluid flow. Using this data, a theoretical model of the system was developed which predicts that nearly all of the load is carried by the fluid (90 percent) in the implant cavity while 27 percent of the load is carried in the fluid for the freshly drilled bone.

The test data and model results strongly support the hypothesis that fluid hydrostatic pressure plays a significant role in load transfer at the bone-implant interface.

3. An evaluation methodology was developed, based on fracture mechanics, for bone cement/metal implant interface failure and it was used to evaluate various metal surface preparations. A four-point bonding specimen configuration was decided upon. Titanium bar stock was obtained and will be machined into proper specimen size. Therefore, as of this report, no data has been obtained ■

HHS, NIGMS GRANT

FLEXIBLE GLOW-DISCHARGE POLYMER LEACHING BARRIERS

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The objective of this project is to study a method of reducing crosslink density in glow-discharge polymers used to modify the surface properties of plastics, without affecting their bulk properties. These studies will include the use of a greater variety of functional groups accessible to this type of polymerization. The reduced crosslinking of these surface polymers should greatly reduce micro-cracking of these materials when they are flexed ■

VAMC NEW ORLEANS

THE MECHANICAL PROPERTIES OF POROUS-COATED ORTHOPAEDIC ALLOY

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This progress report covers the period from 1/1/1982 to 6/3/1983.

Recently there has been increased concern about the use of polymethylmethacrylate (PMMA) cement fixation for orthpaedic devices. Due to problems associated with this system (primarily implant loosening and adverse bone remodeling) research over the past two decades has concentrated on the development of alternative methods of implant fixation. One such system is that of a porous-coated device. A porous metal coating applied to a solid substrate implant has been shown, in vivo, to offer several advantages. These include a higher interface shear strength between implant and bone and a more uniform distribution of stresses throughout the implant and surrounding tissue. However, these advantages may be lost in devices requiring a sintering heat treatment to apply the porous coating, since these heat treatments may have a detrimental effect on the substrate material's mechanical properties.

The objective of this study is to investigate the effects that application of a porous Ti-6Al-4V alloy coating has on the fatigue properties of a Ti-6Al-4V substrate system.

All specimens were tested on a standard R & R Moore High Speed Fatigue Testing Machine which rotates at approximately 10,000 revolutions per minute, while applying a uniform bending moment across the surface of the specimen. Alternating cycles of tension and compression of equal magnitude result in a mean stress equal to zero, and an R ratio equal to negative one. The results were recorded on standard strength versus log number of cycles-to-failure plots (S/N).

Endurance limits of 617 MN/m² (as received uncoated), 62 MN/m² (carbon coated), 220 MN/m² (notched), 377 MN/m² (sinter heat-treated) and 138 MN/m² (porous coated) were found in this study. There was no observed effect on fatigue properties of uncoated as-received or carbon-coated material when tested in saline compared to testing the air.

The uncoated as-received and notched specimens were found to have an equiaxed alpha-beta microstructure. After the sinter heat-treatment of the material (with or without the porous coating) the microstructure transformed into a lamellar structure. This microstructure was found to be continuous from the powder to the substrate in the porous coated samples.

In general, the smooth surfaced as-received material's fracture surfaces exhibited an initiation region, a region consisting of gross fatigue striations (about 25 percent of the surface), and a smooth final-failure region (about 75 percent of the surface). The fact that all initiation sites were found on the smooth surface indicates that the initiation of a crack was probably not related to pores or inclusions. This fact was confirmed by SEM analysis which revealed no evidence of subsurface initiation sites or foreign inclusions. Primary and secondary cracking was observed to occur in directions both perpendicular to and parallel to the alpha grains, for both the porous-coated and sinter heat-treated materials. SEM analysis confirmed that secondary cracking did occur at the alpha-beta interfaces. This fact was confirmed by measuring the average grain width in the fractographs (4.2 m), and comparing it to that found on metallographic sections (3.9 m).

Fatigue cracks in the porous coated material were found to initiate at one or more powder particles. SEM analysis revealed that the morphology of the porous coated fracture surface was similar to that of the heat-treated material in that the failures were generated from the surface, and were evidently crystallographically oriented. The failures differed in terms of the initiation sites. The porous coated samples were found to fail at one or more surface initiation sites associated with the area under the powder particles ■

VAMC SAN FRANCISCO

THE EFFICACY OF RADIOLUCENT TOTAL HIP SURFACE REPLACEMENT

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The theses to be tested in this research are: That (i) the use of materials with low moduli of elasticity will obviate the stress shielding problem, and (ii) that the use of radiolucent materials for the construction of this hip surface replacement prosthesis will allow X-ray visualization of the femoral head.

The research is intended to explore the efficacy of using an ultrahigh-molecular-weight polyethylene (UHMWPE) acetabular component and a carbon femoral component as a low-friction arthroplasty.

We will demonstrate bone response differences through a direct experimental comparison of conventional metal femoral cups and low modulus carbon femoral cups, and will correlate the findings of finite element stress analysis with the quantitative stereology and tetracycline labelling of the femoral head to test the stress-shielding concept.

This study uses dogs as the animal model. Phase 1 consists of 8 unilateral hip surface replacements, using a carbon femoral component and a polyethylene acetabular component to be maintained for 12 months postoperatively. Phase 2 consists of 12 dogs who will undergo bilateral surface replacement, to permit direct comparison of the carbon femoral component with the metal femoral component, each dog serving as its own control.

Evaluation studies of dogs will include forceplate gait analysis, roentgenographic studies and pathological evaluation at necropsy. At necropsy, gross pathological findings will be noted and the hips will be preserved for histological evaluation. Sections will be prepared using hard tissue techniques and quantitative trabecular stereology will be utilized to analyze the bone trabecular thickness and orientation.

The necessary equipment has been procured and experimental protocols have been defined and locally approved. The components for the hip arthroplasty have been purchased and implantation of the devices for the Phase I studies is scheduled for July and August 1983 with device retrieval August 1984. Phase 2 implantation will commence as soon as possible ■

theses to host bone. The techniques or parameters to be investigated are:

(a) Variation in cement thickness;
(b) Pressurized application of low viscosity cement;
(c) Perforation of residual bone tissue with anchoring holes;
(d) Preservation of subchondral bone; and
(e) Metal backing of the acetabular component.

These factors will be investigated, both individually and in combination, in human hip specimens. The specimens will be removed from available cadavers at the time of autopsy, frozen, and then thawed as needed for experimentation. Strength of fixation of both femoral and acetabular components will be determined after subjecting the specimens to an experimental protocol designed to simulate dynamic loading in vivo during the immediate postoperative period.

It is expected that this study will help identify optimum cementing techniques that will improve clinical performance of hip resurfacing prostheses with respect to security of fixation.

The principal project activities during this start-up period have been initial procurement of required cadaver specimens, and the design of fixtures for securing the prepared specimens for cyclic loading and for subsequently testing the strength of fixation ■

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VAMC SALT LAKE CITY

INVESTIGATION OF CEMENTATION TECHNIQUES FOR HIP RESURFACING PROSTHESES

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This is an initial report for a project which began just 3 months before the end of the specified reporting date. Therefore, the principal purpose of this report is to describe the work proposed.

Loosening has proved to be a major clinical problem in the use of hip resurfacing prostheses. However, modified cementing techniques have been reported to decrease loosening in conventional total hip arthroplasty. In this project it is proposed to investigate the effect of such modified techniques on the attachment of Wagner hip resurfacing pros-

NIH MUSCULOSKELETAL

POROUS PLASTER-COATED FEMORAL PROSTHESES

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The objective of the proposed research is to test the hypothesis that the bone ingrowth into porous plastic coatings on femoral prosthesis (in dogs) can serve as the attachment vehicle for the cement-free fixation of joint implants. Specific aims include the determination of the change in tissue response (including bone ingrowth) with (i) position along the medial and lateral aspects of the prostheses, and (ii) wth implantation time (through 2 years).

Thirty porous polysulfone-coated cobalt-chrome canine femoral prostheses will be implanted into 30 adult male English foxhounds (2 years old; 30–35 kg). Clinical evaluations will include radiography and radionuclide bone imaging. Postoperatively, the ani-

mals will be maintained on an active, quantitated exercise program.

Five dogs will be sacrificed at 1, 2, 4, 6, 12, and 24 months. Perfusion fixation of the hind limbs will be performed to insure preservation of tissue structure. Femoral specimens will be allocated for microradiography and ground sectioning, undecalcified Jung Model K microtomy, and decalcification and conventional paraffin techniques. The microscopy sections will be analyzed using histomorphometric techniques. Linear and areal measurements of features in the histological sections will be obtained using a digitizer board/computer system in conjunction with a drawing tube mounted in a light microscope. Histomorphometric parameters, including the percentage each of bone, osteoblastic activity, osteoclastic activity, marrow, fibrous tissue, cellular infiltrates, and others, will be computed for the tissue within and adjacent to the porosity along the medial and lateral aspects of the prosthesis. Fluorochrome bone labeling will be employed to determine rates of bone turnover.

The quantitative histology procedure will allow for the distinction of differences in the tissue response to the prosthesis: (i) at different points along the femoral stem; and (ii) with implantation time. These data will not only serve to begin to qualify porous coated prostheses for clinical use, but should also provide a better understanding of bone formation and remodeling behavior. Unoperated femurs will serve as controls ■

NIH MUSCULOSKELETAL

MECHANICS OF NORMAL, ARTHRITIC, AND PROSTHETIC KNEES

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Osteoarthritis, particularly of the knee, is a major crippling disease. Although mechanical factors are universally assumed to play a major role in the pathogenesis of osteoarthritis, its initiating mechanisms remain obscure. From available evidence, it is plausible to assume that disturbances in articular contact pressures serve as a common pathway in the degenerative process. Yet few direct measurements of contact pressures in normal and pathological knees are available. Existing data are derived from cumbersome experimental procedures which cannot be used effectively in large scale investigations. In addition, few studies have been directed toward the experimental evaluation of pressures following surgical reconstructive procedures commonly applied to the knee. As a result, despite recent improvements in diagnostic accuracy from arthroscopy, there remain major uncertainties and controversies in the clinical treatment of chondromalacia, meniscal and ligamentous lesions, and in the use of tibial osteotomy for the treatment of degenerative arthritis. Since the clinical outcomes of these procedures often cannot be evaluated for more than 10 years, experimental evidence on which to base objective treatment approaches to the knee is urgently needed.

This investigation uses pressure-sensitive films (PSF) in loaded cadaver knee joints to address these clinical issues. The PSF is evaluated by computer processing of its image obtained with a videodigitizing system. Bi-planar radiography of knees with implanted metal markers is used to monitor changes in knee kinematics due to the experimental manipulations. These methods are used to evaluate the efficacy of capsular reconstructive procedures, distal realignment, and elevation of the tibial tubercle in the treatment of chondromalacia. Normal tibiofemoral contact pressures are also measured, the effects of meniscal injury and ACL (anterior cruciate ligament) laxity and separate are studied. The use of partial vs. total menisectomy is compared, and changes in contact pressure with primary ACL repair are evaluated.

The long-term objectives are to resolve these clinical uncertainties in treatment of the knee and to shed light on the role of cartilage contact pressures in the pathogenesis of osteoarthritis ■

VAMC NEW ORLEANS

RETRIEVAL AND ANALYSIS OF ORTHOPAEDIC IMPLANTS

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Period covered, 1/1/83-6/30/83.

As part of an on-going implant retrieval and analysis program, the clinical performance, corrosion characteristics, and metallurgical properties of 83 bone plates have been studied. These implants were all fabricated from 316L stainless steel.

Summary — Clinical histories indicate that many surgeons consider bone plates as permanent implant devices. However, the results of this study demonstrate that a high percentage of the devices are performing unsatisfactorily at all time periods. This was due, no doubt, in some part to the significant corrosion exhibited by the stainless steel material used to fabricate the devices.

The need for corrosion reduction is apparent. It is possible to reduce the degree of corrosion by the use of a smaller grained and microscopically cleaner 316L stainless steel in the manufacture of these devices. Therefore, higher standards for the stainless steel used for implant devices and a higher level of quality-control by the manufacturer seem appropriate. Our data suggests a standard of 7.5 or finer for the grain size and no more than 1.0 for the thin inclusion content as an improvement over the current ASTM standard (F138-76) ■

NSF

THE STUDY OF FATIGUE MECHANISMS IN A 3D CARBON COMPOSITE

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This research program seeks to learn the failure mechanisms of multidirectionally-woven carbon-carbon composites when subjected to fatigue loading, and characterize this material's potential for use in internal prosthetic devices, e.g., hip and knee implants.

The major objectives in this initial phase are to:

1. Discover failure mechanisms and fatigue strengths of a typical fine weave 3D carbon-carbon to determine which parameters (density, matrix pocket shapes, etc.) bear most heavily on fatigue life. Where is the breakdown occurring and at what stress level, cycle, etc?

2. Make a quantitative assessment on the suitability of multi-directional carbon-carbons for implants from a strength and fatigue properties point-of-view.

This is Phase I of research solicited under the Small Business Innovation Research program. If this preliminary work shows a potential for carbon-carbon, follow-on effort will focus on all the design parameters for specific applications such as hip or knee implants ■

NUREP

THE INTERACTION BETWEEN TOTAL KNEE REPLACEMENT GEOMETRY AND KNEE LIGAMENTS

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Loosening of the tibial component is a major factor in the failure of total knee replacements (TKR). This project is intended to identify those ligamentous constraint forces which increase interface stresses to a level which may contribute to the loosening process and thus to ultimate failure of the TKR. The resulting information from this project will form the basis for potential implant design changes, alterations of TKR surgical procedures, guidelines for choosing existing knee implant designs when faced with various clinical situations, and recommendations for improved rehabilitation and orthotic treatment of postoperative knee implant recipients.

The current specific question to be investigated is whether or not the geometry of a knee implant's tibial component should allow retention of one, both, or neither of the cruciate ligaments. Two methodologies are being used to address this issue.

One portion of this project involves the development of an improved biplanar radiographic technique, and the application of this technique to predict in vivo ligament lengths and forces in human subjects with total knee prostheses during actual static joint load conditions. This information will help answer the above cruciate problem statement: keep ligaments if they are functionally load-bearing, and sacrifice them if they are not.

During this reporting period, different and improved computational schemes for the biplanar radiographic technique utilizing alternate algorithms were developed. A mechanical calibration device was built and used to determine the sensitivity of the technique to various error sources.

The biplanar radiographic technique was also applied to in vitro knee specimens containing actual implant components. The ligaments of these specimens were instrumented with force-measuring buckle transducers, such that during application of external load states to the knees, the prediction of ligament forces by the biplanar radiographic technique could be compared with the directly-measured buckle forces. Significant ligament forces (or their absence) were correctly predicted in 14 of 18 ligament load states. After further refinement, the radiographic procedure will be applied to actual patients.

The second phase of this project is to investigate the initial postsurgical state of the knee with a TKR by experimentally using an electrogoniometer (and computer-based data acquisition system) and buckle transducers in a series of knee specimens, in conjunction with an analytical force analysis and finite element stress analysis, to determine ligament and joint contact forces, as well as interface stresses (potential for loosening), for various existing ligament-TKR design combinations. During this reporting period, a prototype of an improved electrogoniometer was constructed, and the development of calibration and data reduction schemes were initiated. An improved external load device was designed and is being built. Also during this period, several

preliminary analyses were performed using buckle transducers (without motion measurement) to measure ligament forces in knee specimens with/without TRK components during various external load states. It was found that (i) ligament forces were near normal in a knee with a semiconstrained implant when both cruciate ligaments were present, and (ii) when the anterior cruciate was excised, the sum of both collateral forces increased an average of two and a half times, implying that the joint contact forces also increased for equilibrum to occur ■

VAMC NASHVILLE

PATHOKINESIOLOGY OF ANTERIOR CRUCIATE LIGAMENT DEFICIENCY

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Rotational instability of the knee joint following rupture of the anterior cruciate ligament is recognized by many orthopedists as a major problem in the active individual. In many persons, absence of this ligament leads to progressive instability, functional disability, and knee-joint deterioration.

To prevent that sequence of events, numerous technical solutions (including repair and/or reconstruction of the anterior cruciate ligament and rehabilitative strengthening) have been proposed. However, a significant percentage of patients with an absent anterior cruciate ligament have no functional disability and have little or no objective instability. In these individuals, progressive instability and knee joint deterioration do not seem to occur.

This obvious discrepancy in the clinical course of patients raises multiple questions regarding the nature of the knee with an absent anterior cruciate ligament and the appropriate treatment for this deficiency. A major problem for the orthopedist in attempting to evaluate the multiple alternatives available is an incomplete knowledge of the biomechanical alterations of the knee joint produced by an anterior cruciate ligament tear. In addition, little is known about the response of the patient to these alterations in order to compensate for this injury. Documentation of instability has been largely clinical in nature, based upon nonfunctional evaluations and using inexact descriptive tools. The inability to precisely describe the deficit involved has made evaluation of treatment modalities even more difficult.

The objectives of this project are to define the knee kinematics and kinesiology in normal individuals and in both the functionally compromised and the functionally able patients with anterior cruciate ligament deficiency. The testing tasks will be level walking, pivoting, and controlled exercising, using gait analysis and isokinetic techniques ■

VAMC EAST ORANGE

STUDENT PROJECTS IN THE DEVELOPMENT OF REPLACEMENT LIGAMENTS AND TENDONS

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Computer Graphics Analysis of Knee-Joint Kinematics — The purpose of this study is to develop a computer graphics procedure which will perform three-dimensional kinematics of the knee joint. Computerized tomography was used to generate the geometry and the shape of the joint. A three-dimensional computer graphical representation of a knee joint is developed.

An analytical method is developed that includes the computations to obtain cross-sectional shapes of the tibia and femur at given locations, a pictorial representation of the two bones from any viewpoint (360 degrees of azimuth, 90 degrees of elevation), and the kinematics of coupled joint motion using Euler angle transformations. Realistic coupled rotations have been simulated. The procedure demonstrates that if the coupled rotations are not chosen properly, bone-to-bone interference results.

The two major factors considered in this kinematic analysis were the flexion/exterior-rotation coupling curve, and the position and direction of movement of the instant center. The kinematic analysis was performed for a maximum of 130 degrees of flexion, with maximum exterior rotations of either 8.8 degrees or 15 degrees. Two types of coupling curves, straight line and exponential approximations, were utilized. The instant center was allowed to move either 10 mm distally and 10 mm posteriorly, or 10 mm distally only. It was found that the coupling curves with maximum exterior rotations of 8.8 degrees or 15 degrees have little effect on the kinematics and it appears to be a less significant factor. The proper instant center height for the knee under investigation was 30 mm. If this height was reduced, interference was observed. The movement of the instant center is also an important consideration; when the instant center was allowed to move posteriorly and distally, interference was observed at the higher flexion angles. However, when it was allowed to move posteriorly only, the interference disappeared. This result tends to agree with Crowninshield's.

In Vitro Fibroblast Cell Culture System — The second project facilitates the study of degradation rate and tissue regrowth rate control. With a fibroblast cell culture system, the degradation of the implant can be quantified and the various methods of acceleration of tissue growth (i.e., growth hormones, Vitamin C) can be studied in an in-vitro model.

The experimental model utilizes 14-day-old Sprague-Dawley rat tendon fibroblasts. The extensor tendons have been removed from the hind legs of the young rats and grown as explants on implant surfaces. It has been found that the cells do not adhere to PLA sheets since the surface is continually dissolving away. This property of PLA may become an advantage in gliding tendon repair and replacement. However, when the tendon explants are placed on a sheet of 10-μm carbon fibers, cells rapidly migrate out along the fibers. Within 1-3 days after the start of the explant culture, fibroblasts from the explant begin migrating out of the tissue onto the carbon fiber substrate.

In a second series of experiments, RTF cells were cultured on filamentous carbon, Dacron, polyethylene and nylon.

The third series of experiments was designed to determine whether the cell orientation previously reported had an effect on the rate of tissue outgrowth on these fibers in vitro. RTF cell colony formation rates were quantified on filamentous carbon, Dacron and polyethylene. Rat tendon explants were cultured on single fibers of the three substrates and the distance from the explant to the cell farthest from the explant on each fiber was measured at 24-hour intervals on live cultures over a 9-day period. There were no statistical differences in the outgrowth rates of RTF cells of the three substrates. These results indicate that the surface characteristics of these fibers affected cell orientation but not outgrowth rates.

In a fourth series of experiments, RTF cells were cultured on standard dishes and on filmentous carbon and the cell growth rates were quantitated. When RTF cells were cultured on standard dishes their numbers increased slowly from days 0 to 3. Between days 3 and 6 the number of cells increased very rapidly. From days 6 through 8, when the cell monolayers became very dense, the increase in cell numbers slowed and stopped as the cell monolayers reached confluence. The growth rates of these cells were similar to the growth rates of other types of cells cultured on collagen fiber lattices.

These studies indicate that synthetic fiber materials such as filamentous carbon have a strong influence on the growth characteristics of RTF cells in vitro. This type of cell-substrate interaction has been largely unexplored. The experiments reported here are expected to help make it possible to use synthetic fiber implants to rebuild damaged tissues in vivo ■

LOWER LIMB GENERAL

VAMC DALLAS

FRACTURE FIXATION AND HEALING

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Results — Initial testing showed that the impact, using a soft rubber tip on the instrumented hammer, although comfortable to the patient, did not contain a frequency spectrum broad enough to stimulate the higher natural frequencies reported in the literature. The half-power frequency of an impact utilizing a

rubber tip was 128 Hz and did not contain any energy after 350 Hz. In contrast, a hard plastic tip on the hammer produced a half-power frequency of 290 Hz with energy content to 1000 Hz. The hard plastic tip not only excited the higher natural frequencies but increased the overall signal strength ■

VAMC KANSAS CITY

BIOENGINEERING ASPECTS OF FRACTURE HEALING: QUANTITATIVE ASSESSMENT

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A quantitative method of evaluating bone healing would greatly aid not only clinical management but also the assessment of new methods for stimulating bone healing. (Radiographic evaluation has been shown to correlate poorly with bone strength. We have previously published a clinical pilot study suggesting that dynamic bone scanning could distinguish between normally healing fractures and delayed healing or non-unions

Bilateral osteotomies at the junction of the proximal and middle thirds of the ulna were made, using a power saw, in eight canine subjects (hound dogs). Measurements were made pre-osteotomy and periodically for up to 20 weeks.

Measurement of fracture healing of long bones using the resonant frequency response. — A method for monitoring the healing of long-bone fractures has been developed and is being evaluated. The method is based upon the percussing and auscultation method originally proposed some 60 years ago, but the device used to monitor the healing is a microprocessor-based instrument which uses charge-coupled-device technology to perform, in real time, the Fourier transform of the impulse response of a bone.

Tests on 38 patients at the University of Kansas Medical Center and 7 patients at the VA Hospital in Kansas City showed significant differences between normal and fractured limbs.

Modal analysis characterization as a toll for assessment of fracture healing in long bone. — Due to their anisotropic material structure, complex geometrical shapes, and the complex damping characteristics of the surrounding tissue, the vibrational behavior of long bones is extremely complicated. A better understanding of the sonic method can be achieved by first applying the technique to similar but less complex structural systems and then progressing, one step at a time, to the complete long-bone system.

Initial tests were conducted on 18-inch-long, one-inch outside diameter, cylindrical specimens of seven different types of material.

Three different instrumented impacting systems were investigated: (i) a hard plastic-tipped hammer; (ii) a physician's reflex hammer; and (iii) a soft rubber hammer. Both a microphone pickup and an accelerometer were used for the output signal. The input impulse signal was monitored with a force transducer.

The comparison between pickups (i.e., accelerometer versus microphone) indicated that both do an adequate job in providing amplitude and frequency information: however, determination of the modal shapes requires the use of an accelerometer because the microphone cannot distinguish between positive and negative signals.

In vitro resonant frequency measurements of the human tibia. — Osteotomies of the right and left tibia of six cadavers were studied to simulate conditions during fracture healing as a "reverse fracture healing" process. Data were taken on the intact leg (thigh removed); on the tibia and fibula with the interosseous membrane intact but with the foot and all soft tissue removed; on the tibia alone; and on the tibia alone with progressively deeper transverse cuts at a site ⅓ the length of the tibia from the distal end. In every case, the major resonant frequency peak increased and became more sharp as the soft tissues were removed. The damped frequency is equal to the undamped frequency times the square root of one minus the square of the samping factor.

These preliminary results support the use of this method in the assessment of fracture healing. Frequency changes are large, which reduces the requirement for extreme accuracy in their measurement.

Assessment of fracture healing by dynamic bone scanning and resonant frequency analysis. — Using the criterion of the return of resonant frequency to the normal value, this technique agreed with the histologic data in 13 of 16 cases. Of the 11 cases in which union was indicated by both the resonant frequency technique as well as the histological findings, in 10 cases the techniques identified the time of union

within 2 weeks of each other. The dynamic bone scan data failed to precisely determine the time of union.

One of the shortcomings of this study was the difficulty of obtaining animal cooperation during the awake resonant-frequency determination. Therefore a second study has been conducted during which the resonant frequency studies, as well as dynamic bone scan data, have been collected under short-acting anesthesia. Furthermore, animals have been sacrificed both early and late to allow mechanical determination of fracture site stiffness which will be correlated with the resonant frequency data.

A more suitable study would be one in which fracture site stiffness is obtained in vivo throughout the fracture healing period. To accomplish this an in vivo four-point bending device has been fabricated. This device has been tested and is now being used in a third phase, in which fracture site stiffness and resonant frequency changes will be measured throughout the fracture healing period ■

NIH MUSCULOSKELETAL

INTERNAL FIXATION PLATES FOR FRACTURE MANAGEMENT

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The objective of this research is to improve the understanding of stiffness requirements of internal fixation plates used for long-bone fracture management. The hypothesis, based on the numerical analyses and bench experiments performed during the current funding period, is that moderate plate bending and torsional stiffnesses are important for early treatment of fracture.

Another hypothesis to be tested is that the low axial plate stiffness may play a significant role in the structural and mechanical properties of the underlying bone during its recovery following plate removal.

The experimental animals will be sacrificed at various time intervals, and the plated and control bones will be evaluated by a multidisciplinary approach. Specifically, stiffness parameters of whole bone, and mechanical and structural properties of bone from various anatomical quadrants, will be evaluated. The vascularity of bone — in the area beneath the plate in particular — will be studied. Hard tissue processing for microradiography and tetracycline labeling for quantitative estimation of new bone formation as well as cortical porosity will be done. In addition, the morpho-metric evaluation procedure will yield dimensional properties, such as cortical area, medullary canal size, and cortical thickness. The biochemical analyses will include ash content, bone mineral, and organic matrix contents. This correlative study will be of importance in order to evaluate the quality and quantity of bone during healing and remodeling and its relationship to the variables of various plate stiffnesses. Ultimately, the experimental data will be used as a basis for the recommendation of clinical treatment of long bone fractures with internal fixation plates ■

NIH MUSCULOSKELETAL

HEMODYNAMIC FACTORS IN FRACTURE HEALING

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The principal purpose of the project is to examine the interaction between mechanical and biological factors in fracture healing. The effect of the type and the stiffness of the fixation device on new bone formation in fracture healing will be studied. The major techniques will be morphometric to quantitate and qualitate new bone formation, biomechanical testing of the strength of the healed bone, and microsphere arteriolar blockade for blood flow measurements.

Initially, plates will be compared to external fixators by using each on a standard tibial osteotomy in the same animal. Then the effects of stiffness of immobilization will be examined by using varying configurations of percutaneous pins with the external devices. Six half-pins (three above and three below the fracture site) will be compared to four half-pins (two above and two below), and biplanar fixation will be compared to one-plane fixation. Finally, the possible benefits of compression of the external fixation device on fracture healing over fixation in neutral position will be explored. Possible bone pressure necrosis due to localized high stresses, both at the fracture site and at the pin bone interface, will be studied. Pin curvature shown on the X-ray will be used to assess the compressive forces, and titanium pins will be used to prevent permanent deformation.

Blood flow will be measured at stated intervals using labeled microspheres. At the end of the experimental period, 120 days, the fracture will be examined for strength of healing by biomechanical testing, and the amount and quality of new bone will be estimated by morphometric examination ■

NIH MUSCULOSKELETAL

MOLECULAR BIOLOGY OF FRACTURE INJURY AND REPAIR

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The overall objectives of this project are: (i) to identify and characterize the critical events of osseous repair in animal models following fracture, and (ii) to assess the effect on the biological repair process of different fracture stabilization modes and/or altered bone metabolism. The goals for the proposed 3-year period fall into two areas:

1. Completion of characterization of the biochemical events that demarcate the stages of fracture healing and the correlation of these events with morphological, radiographic, and biomechanical changes during healing as affected by degree and mode of fixation. Chemical parameters to be measured are the composition and concentration of proteoglycan, collagen, mineral, and lipid. Techniques include molecular sieve chromatography, SDS slab electrophoresis, indirect immunofluorescence, crystal analysis, and biomechanical torque testing.

2. Determination of the biochemical and biomechanical effects of altered nutritional and metabolic status (local and distant) on fracture repair in experimental animals. Examples of such alterations are: nutritional osteomalacia, inhibition of prostaglandin synthesis, and systemic fluoride administration.

Current orthopedic approaches to osseous injury, which have been derived from clinical experience and histological characterization of skeletal injury, do not consistently result in adequate fracture healing. Recently developed methodology for studying the biochemistry, histochemistry, and biomechanics of skeletal tissues should permit the characterization of the critical molecular events necessary for successful fracture union both in normal and altered osseous metabolism. Those results will be helpful in developing a nutritional and therapeutic strategy to improve the success rate of clinical fracture healing ■

NIH MUSCULOSKELETAL

ACCELERATION OF FRACTURE HEALING BY ELECTRIC FIELDS

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The objective of this research is to continue to investigate the effects of applied electrical fields on the acceleration of fracture healing in laboratory animals.

The proposed research is designed —

1. To determine the optimum parameters of an applied capacitively coupled field required to accelerate fracture healing in an osteotomized rabbit fibula model stimulated both locally and remotely.

2. To determine the mechanism(s) of electrically induced osteogenesis at the cell level by determining: (i) the responding cell; (ii) the microenvironmental changes occurring in the vicinity of a cathode; (iii) the effect of direct current on the mitochondrial release of calcium from callus chondrocytes; and (iv) cyclic AMP, calcium flux, and surface charge of the cell membrane of osteoblasts grown in monolayer in various capacitively coupled fields.

Methods to be used include histologic, roentgenographic, and mechanical testing of osteotomized rabbit fibulae subjected to various capacitively coupled fields: H^3 thymidine, C^{14} proline, and S^{35} uptake and the protein, DNA, and calcium content (via atomic absorption) of various isolated cells grown in diffusion chambers in the rabbit peritoneal cavity and stimulated with direct current; needle-electrode determination of pO^2 and pH of medullary canal contents in the vicinity of an active cathode, and correlation of these microenvironmental changes with bone formation (as determined by point counting analysis); electron microscopic changes in mitochondrial calcium release in fracture callus chondrocytes stained with potassium pyroantimonate when subjected to direct current; changes in cyclic AMP, calcium flux (using metallochromic calcium indicators and dual wavelength spectrophotometry), and surface charge of cell membranes (as determined from electron micrographs after staining with polycationic ferritin) in isolated osteoblasts grown in monolayer in various capacitively coupled fields ■

VAMC SEATTLE

THE INFLUENCE OF AGE, DIET, AND ACTIVITY ON CORTICAL BONE STRUCTURE AND PROPERTIES

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Previous research efforts centered on acquiring a data base for normal (caged) rats with which the effects of daily moderate (0.05 km/day) and intensive (0.50 km/day) involuntary exercise on bone matura-

tion could be compared. Results showed that rat cortical bone exhibited allometric growth in all parameters measured (animal age and weight, bone length, and structural and material properties). Intensive exercise produced significant ($P<0.01$) bone hypotrophy (decreased cross-sectional growth rate and decreased bone length) as well as significant changes in material and geometric properties, the former attributed to increased bone mineral content. In addition, intensive-exercise animals showed a marked increase in in vitro failure shear strains (in response to applied torsion) over moderate and control (caged) animals. Preliminary results of "non-stressed" (voluntary) exercise, in which the animals are permitted to exercise as often as they wish in specially designed cages with attached exercise wheels, indicate trends similar to those observed for the involuntary exercise group (some animals were observed to run up to 4 km/day).

These results question the prevailing belief that exercise in the growing animal is always beneficial.

Current studies are directed toward in vitro mechanical testing of immature **primate** cortical bone. In addition to determination of anthropomorphic data, torsion and bending test techniques identical to those performed on rat long bones for evaluation of structural and material properties, are being utilized. Furthermore, in vitro cyclic fatigue (strain controlled, physiological rate — 0.6% strain, 0.02 sec^{-1}) and monotonic tensile failure tests are being conducted on turned primate cortical bone specimens obtained from anatomically different regions within the same bone. Results of the latter indicate that (i) fatigue damage accumulates in the tensile phase of fatigue, (ii) fatigue resistance decreases logarithmically with age, and (iii) the fatigue resistance and strength of Ant. > Post. > Lat. > Med. > sections. Results of the torsion and bending tests revealed allometric relationships which parallel relationships developed for rat cortical bone, indicating that scalar differences between animal species for many bone properties exist. In particular, cortical bone appears to optimize structural properties as a function of torque, body weight, and bone length ■

STIMULATION OF REPAIR OF CORTICAL BONE TRANSPLANTS BY IMPLANTATION OF PIEZOELECTRIC MATERIALS: A PILOT STUDY

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The overall goal of this project was to develop and evaluate a new technique applicable to electrical stimulation of repair of those fractures, osteotomies and nonunions in which surgical intervention for structural bone transplantation and/or internal fixation is indicated. Work during the project was divided into two main parts:

1. Evaluation of Osteostim™ Implantable Bone Growth Stimulators (S12 Model), and
2. Pilot Studies on Devices for Bone Stimulation by Implantation of Piezoelectric Materials.

Osteostim™ S12 Evaluation

At the time this investigation began, the Osteostim S12 stimulator, developed by Patterson in Australia, had just been introduced into the USA commercially and was being recommended for use in treatment of nonunions, and bone defects. The encapsulated power supply was designed to deliver a constant current of approximately 20 microamperes. A titanium cathode was designed to be trimmed to appropriate length and inserted as a small coil at the nonunion site. It was felt that this totally implantable unit might be well suited to the needs of VA patients, and deserved evaluation as a preliminary to work with piezoelectric materials.

Results — Electrical failures and wire breakage of the commercial implants limited results, as stimulation was not in progress for an adequate time in several instances.

While these experiments were not entirely satisfactory due to technical difficulties, the overall impression in both the bone defect and bone transplant models was that the d.c. stimulation did not have a major effect on the healing or remodeling pattern. In both models, there were variations but no obvious preponderance of new bone formation or increased remodeling activity on the stimulated side. Furthermore, at 8 weeks, no consistent differences were noted between those stimulated the full 8 weeks and those in whom stimulation ceased at 1–4 weeks due to breakage of equipment.

In view of the many studies which demonstrate effects of electrical stimulation on bone, the negative results found here deserve some comment as follows.

1. In all cases, stimulation was started on Day 1 of surgery. Therefore, the model is not strictly comparable to adding stimulation to an existing nonunion or earlier transplant.
2. In all cases, the cathode location was essentially devoid of pre-existing living bone cells. The results tend to confirm earlier impressions of the Principal Investigator that direct electrical stimulation is ineffective unless the cathode lies adjacent to living bone.
3. In view of the long cathode wire, the current densities applied were very low. The lack of effect seen with these units is consistent with a study reported by Connolly.
4. The S12 stimulator, as first employed, had serious defects due to lead fragility (they were designed for use in areas of minimum lead movement). Suggestions submitted as a result of this study apparently influenced the subsequent manufacturer to incorporate them into a mechanically improved model.

Implantation of Piezoelectric Materials

The purpose of this pilot study was to determine if piezoelecric materials, placed in contact with bone and deformed with bone by physiological loads, can generate potentials which can affect bone healing and remodeling. Due to time limitations, the primary accomplishment of this work was to design and test various modes for implementing this concept, and to lay the groundwork for continuing studies in progress at present. The most promising mode is use of a piezoelectric material bonded to a relatively flexible internal fixation plate.

Results — In total, various plate designs and configurations were tested in a series of 13 dogs as development work proceeded. In brief, in these experiments, no significant differences on bone healing or remodeling were noted between active and control piezoelectric devices, but output was probably inadequate.

The experience gained in working with this new concept in internal fixation during this pilot study is now being extended in an ongoing development project utilizing a modified experimental design, with evaluation by histomorphometric procedures. Quantitative data on output of the piezoelectric devices in vitro and in vivo also is being obtained ■

BONE/GELATIN PARTICULATE COMPOSITE FOR FRACTURE FIXATION

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Three main research objectives exist for the next project period.

The first objective is to seek a better understanding of the relationship between structural composition and material properties of composites. Both theory and experimental evidence indicate that denser particulate packing should give higher composite material strengths. Spherical glass beads 50 to 500 microns in diameter will be used initially at the particulate phase to simplify experimental variables while studying the effects of size, volume fraction, and particle size on material strength properties. Based on these results, appropriately shaped hydroxyapatite and bone chip particles can be produced using turbulent flow abrasion techniques.

Second, a more biologically compatible composite matrix will be developed. Although formaldehyde and resorcinol make up only 3 percent by weight of the current composite and combine to form an inert product, some biologic toxicity may exist. A synthetic polypeptide that cross-links with itself to form a rigid biodegradable material will be studied for use as a truly nontoxic, resorbable matrix. In addition, more effective cross-linking of the fiber reinforcement will be attempted by using a solubilized form of collagen.

Third, in vivo experimentation will continue concurrently with development efforts in particulate technology and matrix biocompatibility. The host response to implants is crucial and cannot be duplicated by in vitro conditions. Determining a particle size for optimum compressive strength, for instance, may conflict with the best particle size for inducing bony ingrowth. Rabbit models will be used for economy of long-term testing. Sheep will be used when larger models are required for mechanical testing of the in vivo structural performance of the particulate composite ■

VAMC SAN DIEGO

EFFECT OF STRESS AND MOTION ON REPAIR OF HARD AND SOFT TISSUES

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This research program is designed to pursue Wolff's Law on tissue healing and remodeling. It is well known that initial immobilization is necessary for tissue healing purposes, but it is also known that prolonged and/or over-immobilization can retard the repair process and also induce the disuse atrophy of the surrounding tissues.

This research program is divided into two areas of concentration. One is the study of the effect of the use of sturdy and large internal fixation plates to immobilize long-bone fractures. These devices are effective in immobilizing long-bone fractures. However, once the fracture is healed, such a "rigid" internal fixation system may be detrimental to normal bone remodeling because the underlying bone is overprotected from normal physiological stresses, and because of that becomes atrophic or osteoporotic.

The second study is to evaluate the effects of motion and stress on ligament repair. Early immobilization is necessary to facilitate soft tissue healing, but prolonged immobilization can result in joint stiffness manifested as contractures. On the other hand, uncontrolled motion may cause increase in ligament length and joint laxity as well as disrupt the repair. Thus, a suitable amount of immobilization, motion, and exercise all seem to be required in order to determine the optimal modality in the repair of failed ligaments.

Tubular Plate Design — In the internal fixation plate study, an experimental plate made of titanium alloy designed to have a tubular cross-section filled with high-density polyethylene is being investigated. A tubular cross-section will permit the desired combination of high bending stiffness and torsional plate stiffnesses to facilitate fixation for fracture union, and at the same time will provide low axial stiffness to minimize stress-bypass effects on bone, to permit more normal bone remodeling.

It has been demonstrated in our laboratory that such a tubular plate, made of stainless steel, has been successful in treating experimental fractures.

The experimental titanium tubular plate, and traditional "rigid" stainless steel solid plates, will both be used to immobilize unilateral mid-shaft femoral osteotomy of dogs. Both the experimental and control plates will be of similar dimensions with respect to length, number and spacing of screw holes, etc. The goals will be to study the effects of short-term (4 and 6 months) and longer terms (9, 12, and 18 months) of plate application. Fracture healing will be evaluated by bioengineering, morphometric, and biomechanical methods.

In the ligament repair study, the medial-collateral ligaments (MCL) of the dogs and rabbits have been studied and a variety of activity conditions have been imposed to determine which set of conditions will maximize the speed and strength of the ligament healing. These regimens include rigid immobilization, cage activity, immobilization plus activity, etc. The method of evaluation includes morphologic, bioengineering, and biochemical techniques.

During this past year, 18 adult mongrel dogs have been used as experimental animals. The MCL's were cut. The animals were divided into three groups: (i) MCL were repaired and the knee was immobilized for 6 weeks, (ii) same as (i) but the knee was immobilized for 3 weeks and left free for 3 weeks activity, and (iii) no repair of the ligament and no immobilization of the knee for 6 weeks. The emphasis of this study is on evaluation of the different treatment regimens. Biomechanical studies include the evaluation of the strength of the repair site using an Instron testing machine; and the varus-valgus laxity of the knee joint using a new device that attaches to the Instron. The tensile test results, and those obtained using the newly constructed laxity device, suggest the following conclusions: (1) early immobilization may have a positive effect in reducing joint laxity, and that complete immobilization may be detrimental after 6 weeks; (ii) immobilization may have an adverse effect on the healing ligament's structural properties compared to groups with earlier mobilization; and (iii) immobilization may aid in the mechanical properties of ligament scar ■

VA RR&D CENTER HINES

A BIOMECHANICAL STUDY OF FIBULAR MALUNION

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Fracture of the ankle-joint complex is a common orthopedic injury. There is clinical evidence that inaccurate fixation of a fractured fibula leads to arthritic and/or degenerative changes in the ankle joint. The purpose of this study is to quantify the amount of fibular shortening or rotation that would significantly

alter the normal pressure patterns in the ankle joint.

A pressure-sensitive film is used to measure the contact area and pressure distribution within the ankle joint of cadaver speciments under compressive loads. The fibula is fractured just above the ankle, and surgical fracture fixation is simulated using a special plate. This plate allows for control of fibular rotation and shortening. The pressure-sensitive film is inserted in the ankle joint and compressive loads are applied to the specimen corresponding to the physiologic loads during the normal gait cycle. The film is later analyzed for contact area and pressure distribution for each loading condition.

Preliminary results indicate that changes in contact area, average pressure, and pressure distribution begin with as little as 2 mm of shortening or 15 degrees of rotation of the fibula. Data from this study is intended to provide an objective treatment criterion for fracture fixation of the ankle joint complex ■

NIH MUSCULOSKELETAL

ORTHOPEDIC SEPSIS: PATHOGENESIS, DIAGNOSIS, AND TREATMENT

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The overall objectives of this project include the examination of the mechanism of sepsis involving polymethyl methacrylate, determination if the hosts' inflammatory or immunological mechanism may be compromised by this polymer, the evaluation of local bone flow following the surgical treatment of osteomyelitis, and the investigation of the ability of the newer noninvasive scintigraphic techniques to differentiate acute hematogenous osteomyelitis from trauma.

The initial objective of this project is to show that methylacrylic acid, the byproduct of unpolymerized methylmethacrylate, is bactericidal and offers protection against wound infection. Acrylic cements such as Palacos® , which leach little methylmethacrylate, are more susceptible to sepsis than Simplex P cement. This objective will be accomplished by quantitating the chronologic leaching of unpolymerized methylmethacrylate and its hydrolysis methylacrylic acid per cm^2 of Palacos® and Simplex P bone cements. The bactericidal activity of methylacrylic acid against common pathogenic microorganisms — *S. aureus, S. epidermidis, E. coli,* and *P. aeruginosa* — will be documented. Finally, the effect methylacrylic acid and the monomer methylmethacrylate leaching from Palacos® and Simplex P have on white blood cell subtype viability and their functional inflammatory and immunological activities when exposed in vitro to amounts felt to represent that occurring from its in vivo utilization will be determined.

The second objective of this project is to evaluate blood flow to osteomyelitic bone with a noninvasive technique (dynamic 99m technetium scintigraphy) and an invasive technique (85 Sr microspheres) following debridement with or without a local muscle flap and antibiotics in the dog. The goal of this study is to determine if the efficacy of a local muscle flap is related to increased local bone blood flow, and if dynamic 99m technetium scintigraphy can be used to monitor treatment with a noninvasive technique.

The third objective of this project is to determine if 111-indium-labeled white blood cell imaging, or dynamic 99m technetium scintigraphy, can diagnose acute hematogenous osteomyelitis between 6 and 168 hours following initiation of the infection in the dog ■

NIH MUSCULOSKELETAL

HEMATOGENOUS OSTEOMYELITIS: ETIOLOGY AND TREATMENT

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The purpose of this project is to study the etiology, pathophysiology, natural history, and treatment of acute hematogenous osteomyelitis and other factors which may influence the direction and duration of this disease.

A standard experimental rabbit osteomyelitic model was developed and was reported in preliminary results. Further refinement and standardization of the model are needed. The model relies on systemically administered bacteria which will create a subclinical bacteremia. One limb is traumatized by minimally slipping the epiphyseal plate of the tibia on a specially constructed press which does not create instability, bone damage, or hemorrhage to the plate. As the bacteria appear to be localized below the area of traumatization in the metaphysis, a typical clinical osteomyelitic condition occurs and prevails. With this model, one is able to control the severity of the disease, predicting and locating lesions.

Using this model, the pathophysiology may be studied at daily intervals, enabling a better understanding of the natural history of the disease. Once an understanding of the progression of the disease has been obtained, other influencing factors such as trauma, immunosuppressants, and dietary deficiences may be applied and the effects carefully monitored.

When the model has been perfected, standard forms of treatment may be applied to the model and their effects studied. This knowledge will give the surgeon greater ability in treating the disease. It is known that early administration of antibiotics is effective in treatment, but later administration is not. These studies are intended to answer the question of whether antibiotics are useful after a certain length of time following the onset of the disease. They could also indicate a point in time when surgery must be used, and predict its success.

The information yielded from this project can enhance understanding of the disease in humans and enable the orthpedic surgeon to treat the disease more scientifically ■

NIH MUSCULOSKELETAL

BACTERIAL COLONIZATION OF SURGICAL BIOMATERIALS

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A variety of biomedical materials, many of which are plastics or metals, are implanted into large numbers of patients in many forms. A disturbingly large proportion of patients implanted with surgical biomaterials (e.g., 1 to 11 percent of all prosthetic hip devices, or 15,000 to 30,000 patients per year) become chronically infected. These infections respond notoriously poorly to antibiotic therapy and may necessitate the removal of the biomaterial with unfortunate sequelae.

Recently developed insights in microbiology have shown that surface adhesion is the first step of the pathogenic process, suggesting that bacteria may colonize an inert surface within the body if they are introduced during implantation of the device or if they are carried to the area by transient bacteremia. It is known that bacteria adhere to inert surfaces (e.g., pipes in cooling towers, rocks in alpine streams, and dental enamel) by means of exopolysaccharide fibers, the glycocalyx.

The discrimination of these processes has obvious importance. It is proposed to continue to recover these adherent bacteria from actual cases of infected surgical biomedical implants and to establish them as adherent populations on a variety of metal and plastic surfaces in vitro. A preliminary direct observation of material from infected internal fixation devices has demonstrated adherent bacteria surrounded by extracellular fibers. These bacteria have been isolated; their adhesion to metal and plastic surfaces by means of their surface polysaccharide has been demonstrated. It is proposed to study the effect of this mode of growth on resistance to clearance by macrophages and on resistance to antibiotics. Development of an understanding of the bacterial colonization of a wide variety of surgical materials should make it possible to select materials and finishing processes that minimize bacterial adhesion and maximize clearance by macrophages. By studying the chemistry of the bacterial exopolysaccharide and its role in antibiotic resistance, one seeks to optimize antimicrobial therapy ■

NIH MUSCULOSKELETAL

STUDIES OF FACTORS AFFECTING ORTHOPAEDIC INFECTIONS

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The research being undertaken is designed to investigate problems of infections in orthopedic patients. One goal of the study is a better understanding of factors leading to wound contamination in open fractures and any infections that might follow such contamination. Various factors including the use of internal fixation devices, methods of irrigation, time between injury and treatment, and underlying diseases are being compared with infection rates and with level of tissue contamination.

An animal model involving open fractures of the hamster femur using an osteotomy saw has been developed to clarify the role of internal fixation in infection. Studies have been done with staphylococcus aureus and will be done with proteus and an anaerobic streptococcus. Studies are also being undertaken in the hamster to investigate host responses, such as sensitivity reactions to the implant, on infection rates. Finally, rapid diagnostic techniques are being investigated for diagnosis of osteomyelitis and septic arthritis using blood, joint fluid, and aspirates. These studies should provide information on the management of patients likely to develop infections ■

NIH MUSCULOSKELETAL

DISTRIBUTION AND PHARMACOKINETICS OF DRUGS IN BONE

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The purpose of this study is to identify and refine those procedures with which the pharmacokinetics of drugs in bone can be accurately and reproducibly studied. This information will then be applied to the study of normal, infected, and avascular bone, and the common principles of antibiotic distribution within bony tissues will be sought.

Bioassay and radioassay procedures in combination with histological and autoradiographic methods will be used.

The end result is intended to provide a clear, practical picture of the location, availability, and quantity of antibiotic in bone, and to provide pertinent scientific information that will be directly applicable to clinical situations ■

VAMC GAINESVILLE

FOREIGN BODY REACTION IN THE LUNG TO INTRAVENOUSLY INJECTED BIOMATERIALS

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During the period from January 1 to June 30, 1983, the standard bead model previously defined in this project has been used to continue studies on the assessment of cellular changes during granuloma formation and the relative effectiveness of both steroidal and nonsteriodal anti-inflammatory drugs. In these experiments, sieved 45–53 μm divinyl copolymer beads were injected into the tail veins of mice, from whence they embolized to the lung. The granulomatous reaction to the beads was quantitated by use of a computerized digitizer. This model system has been used in these studies for observation of the cellular events in granuloma formation and for continued quantitative testing of the effectiveness of anti-inflammatory agents.

Results — Initial adherence of neutrophils could be seen at 3 hours after bead injection and many were still present at 24 hours with few monocytes observed. At 48 hours, when the maximum reaction was observed, both neutrophils and monocytes could be observed in the granuloma ■

VAMC PHILADELPHIA

FLUOROMETRIC PREDICTION OF SUCCESSFUL AMPUTATION LEVEL IN THE ISCHEMIC EXTREMITY

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The adequacy of nutritive capillary blood flow to the skin at an amputation site is a major determinant of the optimum level of amputation. Techniques such as plethysmography, waveform analysis, dye dilution, and oscillometry measure "total" blood flow or pressure to an area but do not document capillary flow to specific tissues. Temperature measurements reflect arteriovenous shunt flow — not nutritive capillary flow. Ultrasound doppler, one of the most popular techniques, assesses arterial pressure; moreover, doppler readings may be spuriously high in patients with noncompliant arteries, a common feature in diabetic patients.

Twenty patients with severely compromised extremities, in whom the optimal level for amputation was not clear, were referred for this study. Each patient was evaluated in two ways:

1. Standard clinical assessment (SCA); this included clinical inspection, ankle/brachial pressures by ultrasound, angiography, photoplethysmography, and pulse volume recordings;

2. Fluorometry (FLUOR); 15 minutes after injection of fluorescein, dye delivery was quantified by placing the fiberoptic probe of the perfusion fluorometer on as many as 75 reading points per leg (3 sec/reading).

All amputations were performed based on SCA. Of the 20 amputations performed, 16 healed without complication; 4 did not heal and required revision. Thus, SCA had an 80 percent overall accuracy with a 20 percent false-negative rate. FLUOR was significantly more accurate ($P<0.05$ by the Chi-squared method) with a 100 percent accuracy rate, despite being shortened to a 20–30 minute test.

Conclusion — Initial studies suggest that fluorometry is a highly accurate way to predict proper amputation levels. It is minimally invasive and accurate. With refinement, fluorometry may prove to be the optimal technique for this assessment ■

VAMC SEATTLE

MORPHOLOGICAL AND CLINICAL STUDIES OF MICROWOUNDS IN ISCHEMIC HUMAN TISSUE

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The purpose of this project is to study in a systematic fashion morphological and clinical features of small standardized wounds created on the lower limbs of patients with severe peripheral-vascular disease (PVD) necessitating amputation. The wounds wil be created with Simplate II bleeding-time device under sterile conditions at locations immediately distal to the planned site of amputation, and at a variety of clinically and biologically relevant time periods, for a study of wound healing.

Wounds will be examined clinically at the time of surgery, then excised from the amputation specimen and fixed for morphological studies. Light and electron microscopy will be performed on the samples. Morphological events of healing will then be compared with normal controls from previous studies, transcutaneous oxygen tension ($TCPO_2$) at the microwound site, the clinical appearance of the microwounds, the outcome of the amputation — and will be related to a variety of risk factors for PVD such as smoking, diabetes, and hypertension ■

VAMC CASTLE POINT

THE USE OF HYDROGEN-CLEARANCE TECHNIQUE IN MONITORING MUSCLE BLOOD FLOW: EFFECTS OF LUMBAR SYMPATHECTOMY ON MUSCLE BLOOD FLOW

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Abstract — The technique of hydrogen clearance has been used in five canines to monitor blood flow in gastrocnemius muscle following sympathectomy. The contralateral nonsympathectomized limb was used as a control. Average blood flow was based on 22 pairs of desaturation data. Average blood flow in the left control limb was 6.08 ± 2.22 ml/min/100g tissue and the right sympathectomized limb was 9.54 ± 3.97 ml/min/100g tissue. Average blood flow increase was statistically significant ($p<.005$) in the sympathectomized limb over the contralateral control. The increase in muscle blood flow following lumbar sympathectomy, if of prolonged duration, may be a valuable adjunct to direct reconstructive arterial surgery in the management of symptomatic arteriosclerotic occlusive disease. The technique of hydrogen clearance is excellently suited for the monitoring of muscle blood flow and may be equally applicable in determining level of amputation ■

VAMC SEATTLE

TRANSCUTANEOUS OXYGEN TENSION AS PREDICTOR OF WOUND HEALING

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Transcutaneous oxygen tension, a noninvasive means to determine local cutaneous perfusion, has been studied for its usefulness in predicting wound healing potential and correlated with the severity of peripheral vascular disease. Transcutaneous PO_2 measurements were made segmentally on the limbs of diabetic and nondiabetic patients with varying degrees of peripheral vascular disease. Results indicate that nondiabetic limbs with $TcPO_2$ values on the foot or below-the-knee less than 20 mmHg are significantly more likely to have rest pain or ulcers, to need an amputation, and to have failure of amputation healing than those limbs with $TcPO_2$ values above 40 mmHg. Results from diabetic patients were similar; however, many diabetic patients have ulcers in the presence of high (greater than 40 mmHg) limb $TcPO_2$. This suggests that ulceration in many diabetic limbs may result from factors other than insufficient cutaneous oxygen delivery.

The healing characteristics of below-the-knee amputations resulting from peripheral vascular insufficiency were correlated with transcutaneous PO_2 values at that level. Results indicate a strong correlation between transcutaneous PO_2 values and amputation healing below-the-knee. All patients with below-the-knee $TcPO_2$ above 40 mmHg healed, healing rate where below-the-knee $TcPO_2$ was between 20 and 40 mmHg was 93 percent and healing rate where $TcPO_2$ was below 20 mmHg was 50 percent.

A human model of peripheral vascular insufficiency has been developed where the brachial artery

*Dr. Matsen and Dr. Burgess, the principal investigators, are with the Limb Viability Laboratory and the Prosthetics Research Study, respectively. Dr. Wyss, associate investigator, is with the Limb Viability Laboratory. The research is a **VA Rehabilitation R&D** Program project.

is occluded while other major vessels remain open. Using this model, a hypertensive response to ischemic exercise and postexercise decrement in $TcPO_2$ was observed as observed in patients with peripheral vascular insufficiency. This model of claudication in normal human subjects appears to be a useful method to investigate the local and systemic effects of ischemic exercise. Results from this series of experiments suggest that $TcPO_2$ measurements made during or immediately after exercise stress may be more sensitive than resting $TcPO_2$ values in people with mild peripheral vascular insufficiency.

Development of a multiprobe transcutaneous oxygen tension monitor has allowed us to begin investigations mapping cutaneous perfusion in arterially insufficient limbs. These studies continue to elucidate the value of transcutaneous PO_2 measurements in the clinical assessment of the circulatory status of localized areas of skin ■

NIH MUSCULOSKELETAL

DIAGNOSIS OF LOOSE OR DAMAGED TOTAL JOINT REPLACEMENT

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The need exists to diagnose correctly the mechanical degradation of total joint replacements. The efficacy of in vivo joint monitoring by means of acoustic emission has been demonstrated. To develop further the technique of in vivo monitoring, the acoustic emission waveform characteristics will be analyzed using correlation plots. This analysis, together with the attenuation results, will be used to increase the effectiveness of the electronic equipment through proper choice of waveform filters.

The development of acoustic emission monitoring requires continuation of an ongoing program to monitor patients from the Hip and Knee Clinics of The Hospital for Special Surgery who are clinically considered to be at high risk of mechanical failure. Correlation of acoustic emission results with other clinical findings will provide a basis for clinical interpretation of acoustic emission results.

The mechanisms which generate acoustic emission will be further examined. Acoustic emission resulting from failures in implant materials such as bone and polymethylmethacrylate did not correlate well with results from in vivo monitoring. Therefore, the contribution of interface failure and cancellous bone failure as the most probable sources of acoustic emission will be investigated using in vitro experiments and finite elements analysis. Composite models will be monitored during loading. Specialized finite element analysis capabilities aimed at determining failure loads and locations in interfaces will be used to correlate acoustic emission results (both experimental and clinical) with analytical predictions ■

VAMC LITTLE ROCK

THE EFFICACY OF SURGICAL AND REHABILITATIVE PROCEDURES OF THE KNEE

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This project is in the second year and concerns the design and development of an instrument to test the efficacy of surgical and rehabilitative procedures of the knee, using cadaver specimens under as good a physiologic condition as possible. The instrument may also be used to determine the characteristics of implantable prostheses and the strength of various attachments for the knee.

The first research efforts to study the knee using a cadaver specimen were performed with a knee-test apparatus designed for this application. The experience with this "machine" led to the present effort to design a stronger and more versatile apparatus that could do a more effective job of testing the knee. Based on the experience with the earlier device, the specifications for the new test instrument were to be as follows:

1. body weight: 200 lb
2. quadraceps force: 500 lb
3. transverse tibial rotation: ±90°
4. tibial torque: ±200 inch-lb
5. medial/lateral tibial motion: ±26°
6. medial/lateral force: ±100 lb
7. flexion/extension: −15° to +130°
8. anterior/posterior angle: ±5°
9. anterior/posterior force: ±25 lb
10. specimen size: 6 to 20 inches overall

Other specifications were that the torque and force controls for the transverse and coronal planes were to have the ability for either or both to be easily disconnected without disturbing their angular measurement capability.

An additional and highly significant feature of the apparatus as compared to the old one is that the entire knee specimen may be rotated while under load about a vertical axis that passes through the

ankle and the hip. This will permit observing (or making incisions on) the posterior portions of the knee specimen while it is under load and while it is being observed from the posterior. Also, the knee may be X-rayed from any direction conveniently, due to this rotation about the vertical axis.

The data channels selected for measurement are as follows:

1. flexion/extension;
2. tibial rotation angle;
3. medial/lateral motion angle;
4. anterior/posterior motion angle;
5. anterior/posterior force;
6. rotational torque;
7. medial/lateral force;
8. body weight; and
9. quadraceps force.

This system will have a force-overload interlock applied to the quadraceps force (500 lb max.) and the body weight (200 lb max.). Any time either of these parameters exceeds the maximum level by 25 lb, the computer will automatically shut down the mechanism by which these parameters may be increased and will annunciate the fact that an overload has been achieved. At this time, only those controls which decrease the values of these parameters will be operable.

The system as described has been completely designed and is about 85 percent complete in its construction. It is anticipated that it will be in operation and taking data within the fourth quarter of this contract period. The greater load capacities and angular motions inherent in this device, as compared to the previous one, along with the ability to monitor all the data channels simultaneously, should provide a system which allows the knee to be studied in vitro under as good a condition as possible ■

HHS NIGMS GRANT

SURGICAL IMPLANTS FOR SUSTAINED MACROMOLECULAR RELEASE

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The objective of this proposal is the development of non-erodible and erodible biocompatible polymeric systems capable of delivering high molecular weight drugs (M.W.1000), such as polypeptides and proteins, after implantation. The development of a system which would control the rate of release of drugs from implanted polymeric substances is also under investigation ■

NIHR REC

A SELF-CONTAINED PORTABLE FORCE AND MOVEMENT MEASUREMENT SYSTEM TO AID DIAGNOSIS AND REHABILITATION OF HUMAN MOVEMENT DISORDERS

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The work described here is a continuation of an effort which started with the specific aim of improving A/K amputee gait-training through development of instrumentation for measurement and biofeedback of gait parameters. As prototype hardware was completed, its general applicability became apparent. Although the immediate focus of the effort remains on A/K gait training, the criteria that guide design decisions are more global. A self-contained, portable, force and movement measurement system has many applications in diagnosis and rehabilitation.

The gait-training aid is a microcomputer-based instrument that has been programmed to provide the following:

1. Threshold and/or proportional audio biofeedback of the prosthesis weightbearing (Is the proper weight being applied to the prosthesis?).
2. Average peak weightbearing during a series of steps.
3. Percentage of stance cycles during which the adjustable weightbearing threshold was attained.
4. Threshold and/or proportional audio biofeedback of hip extension angle (Is the person standing erect during stance?); and
5. Percentage of cycles during which the hip extension threshold was exceeded during stance.

During the past year, several subtle changes have been made in the instrument's software, but the main effort has been directed toward improved force and movement transducers.

In order for a weightbearing transducer to be clinically acceptable, it must be compatible with existing postoperative prostheses and training procedures. Such a transducer has been designed and is currently being built. It uses a thin cylinder of elastomer to isolate the axial load on the prosthesis from the large bending moments which occur in the shank. This allows a strain gage to measure one type of loading without being substantially affected by large stresses in other directions.

The movement transducer has also changed dramatically. The new system is essentially a radio direction-finder. A small transmitting antenna is placed on one body segment and a crossed pair of receiving antennae is placed on another body seg-

ment. Appropriate processing of the signals from the two receiving antennae yields a very well-behaved indication of the angle between the transmitter and receiver.

A prototype of this radio goniometer has been built ■

VAMC DALLAS

ASSESSMENT OF ENDURANCE OF QUADRICEPS AND GASTROCNEMIUS MUSCLES BY POWER SPECTRUM DENSITY TECHNIQUES

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The University of Texas Health Science Center at Dallas, Orthopaedic Surgery, and The University of Texas at Arlington, Biomedical Engineering.

This project represents a continuation of previous work concerning the relationship between myoelectric signals and muscle function during exercise. The mission is to document, in normal individuals and rehabilitating patients, a decrease in mean or median power frequency during exercise as fatigue develops.

Power spectrum density analysis of myoelectric signals are done using a Digital Equipment Corp. (DEC) LSI 11/23 minicomputer. Analog signals are filtered and digitized at a sample rate of 2048 hertz and stored on floppy discs. A fast Fourier transform is done on consecutive 250-millisecond time segments to produce a 512-point power spectrum density periodogram. Consecutive sets of eight periodograms are averaged and used to obtain mean power frequency.

In a study with 14 young adult normal males we compared gastrocnemius muscle fatigue at 50 pecent MVC, along with contraction characteristics (maximal rate of torque development and electromechanical delay time), and muscle fiber types (from a single biopsy). Subjects included endurance athletes and athletes with explosive strength or speed. The latter athletes, as expected, had a greater relative proportion of fast-twitch fibers; also, they had a higher initial mean or median power frequency and a more rapid drop in frequency as fatigue progressed. End-of-trial frequencies were approximately the same for both types of athletes.

In another pilot study we examined quadriceps muscles following total knee replacement surgery of five patients seen up to 6 weeks after surgery. Data revealed that fatigue rates decreased and initial mean and median power frequencies increased consistently over time, indicating that the general test procedures were capable of monitoring post-surgical rehabilitation of lower limb function.

Studies to date indicate that a reasonably standard method (rms or integrated value of voltage associated with the myoelectric signal) that has been used to measure endurance is not as reliable as measurement of changes in mean or median power frequency. Little difference exists between mean power frequency shifts and median power frequency shifts. We remain optimistic that continued progress by investigators throughout the world may bring greater objectivity to analysis of muscle function in a clinical setting ■

VA RR&D CENTER HINES

EFFECTS OF FOOT ABNORMALITIES ON WEIGHT-FLOW AND PRESSURE DISTRIBUTION

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Structural and functional foot abnormalities are considered to play a significant role in the development of focal points of pressure and trauma. There is clinical evidence that points of pressure and trauma are areas most likely to undergo pathologic changes in the neurotrophic foot. This quite commonly leads to ulceration, infection, gangrene, and amputation. The treatment modalities for such pathologic changes include the use of foot orthoses, modification of shoes, and surgery. The objective of these treatments is to restore a more "normal" pattern of weight-flow and pressure distribution on the plantar surface of the foot within the environment of the shoe during gait.

The purpose of this study is to develop a measurement system to quantify weight-flow through the foot and the pressure distribution on the foot within the shoe environment. The feasibility of using this device in the clinic as a diagnostic and treatment evaluation tool will then be investigated.

A measurement system capable of quantifying this pressure distribution in real time is being developed, utilizing an insole instrumented with a flexible array of thin-film piezoelectric pressure transducers. Data from a control group of normal subjects and patients from the Hines VA Hospital will constitute the device evaluation study ■

LOWER LIMB PROSTHETICS
GAIT ANALYSIS

NIH MUSCULOSKELETAL

DEVELOPMENT OF CLINICALLY APPLICABLE MODEL OF GAIT

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The aim of this research is to improve current gait analysis techniques through the use of quantitative engineering and mathematical techniques. Specifically, it will be determined: (i) which clinical treatments would be expected to yield the greatest improvement in a pathological gait; (ii) what the predominant response of a patient is to treatment; and (iii) whether the subject's response to treatment is the same as that intended clinically when the treatment was prescribed. Each of the aims of this project will be evaluated in terms of the mechanical response to a model of the gait of the subject under consideration.

The treatment of pathological gait has been greatly aided by the development of the modern computer-based gait laboratory. However, gait laboratory measurements of isolated mechanical parameters yield an incomplete description of gait. Such a description is highly subjective. Employing a model for gait would lend a greater objectivity to such clinical analyses and greatly improve the potential of clinical treatment, which is the long-term objective of this research ■

NIHR REC

OBJECTIVE INTERPRETATION OF GAIT ANALYSIS DATA

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In the past year a random sample of 125 patients who were diagnosed as having cerebral palsy and had gait studies in our lab has been evaluated. The measurements associated with leg motions in three dimensions were used to form a time series, represented by a 13-term Fourier series for each frame, using the least squares method. For each patient the set of coefficients obtained for a given angle was used to describe the corresponding angular motion. Various statistical and clustering methodologies were then applied to the clinical gait kinematic data to determine if patient groupings of cerebral palsy could be established which would reflect a given patient's diagnosis and subdiagnosis. In the Kth nearest-neighbor clustering procedure, four subpopulations were identified from the modes of a uniformly consistent estimate of the underlying measurement-space density, and proved the most promising.

Analysis-of-various techniques were used to identify the key elements in the locomotor disorder that established the given dysfunction. A recursive partitioning classification scheme was utilized to examine how a given patient's gait pattern changed over time (with or without treatment). Graphical profiles and F-ratios were used to identify those individual measurements which were most useful in distinguishing the membership of the various observed clusters.

It was found that the four resulting clusters can be identified with different severeness levels of abnormal gait. Walking velocity, and patterns of hip and ankle movements, were seen to be markedly different for each cluster rather than for age or subdiagnosis (hemiplegia, diplegia, etc.). Traits associated with patients in two clusters were identified with severe gait pathologies, while the remaining three clusters exhibited characteristics more closely approximating normal gait. For the hip and ankle movements, it was seen that the absolute relative magnitudes of the Fourier coefficients for Cluster 3 tended to be small, indicating less angular motion in the hip and ankle than the other clusters.

No systematic pattern across clusters could be detected for knee coefficients.

Most of the patients in the two poorest-walking groups were diagnosed as having quadriplegia, while none of the patients in the best-walking group had that diagnosis. On the other hand, a patient diagnosed as having diplegia can be in any one of the five identified clusters; hence, the present diagnosis system is not suitable for indicating the functional status of a cerebral palsy patient.

Subsequent to cluster analysis which is useful for groupings-identification, it was important to develop a classification scheme so that new patients can be assigned to one of the identified clusters. Such a classification scheme was felt to provide a useful typology for classifying cerebral palsy patients. A recursive partitioning decision rule was used to construct a classification scheme based on the group-

ings obtained by the clustering method. Using this classification rule, it was demonstrated that the effects of corrective measures such as surgery or assistive devices on the gait patterns of individual patients can be examined. The results, in general, suggest that the effect of an operation or assistive device may well be more dependent on the classification scheme developed than upon the subjective evaluation of gait as determined by clinicians ■

NIHR REC

MECHANICAL ENERGY OF ABNORMAL GAIT (ANALYSIS)

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Normal walking minimizes energy expenditure. Since muscle forces are needed to change the mechanical energy levels of the body during walking, the amount of mechanical work during walking at a given speed would seem to indicate the minimum metabolic energy needed. Knowing this relationship, we would then be able to determine the relationship between lower limb joint abnormalities and oxygen consumption. No previous study was found to have evaluated this relationship.

A study was undertaken to determine the relationship between each of three mechanical work (energy) parameters and the metabolic energy cost of normal gait. These parameters were: (i) mechanical work done on the center of mass; (ii) total-body segmental mechanical work; and (iii) the sum of the average absolute joint moments present in the lower limbs.

Six normal adults (3 male and 3 female) between the ages of 29 and 36 were used as subjects. Each walked at 5 different speeds: very slow, slower than normal, normal, faster than normal and very fast (.87 m/sec to 2.28 m/sec). Five minutes were spent at each walking speed. The expired gases were analyzed continuously and the energy consumption rate (E) in joules per kilogram body mass per second was determined for the last minute of each walk.

Oxygen consumption/kg-sec was found to closely fit a quadratic equation and was highly correlated with velocity (v2r = .93). This relationship agrees well with that found by other investigators. The three mechanical parameters per kg and per second also closely fit quadratic equations and were highly correlated with velocity V2 (.91 for center of mass, .81 for segmental work per sec, and .92 for joint moment). They were also highly correlated with oxygen consumption/kg-sec (.89 for center of mass, .79 for segmental work, and .89 for joint member/kg-sec).

However, the correlation between energy consumption per meter and each of these mechanical parameters per meter is not high (only .28 for center of mass, .18 for total body segmental work and .17 for joint moment).

These results need to be confirmed in patients with spasticity to determine if similar types of relationships exist between energy consumption and these mechanical parameters. Since high levels of co-contraction of antagonistic muscles exist in these patients, relationships may differ somewhat from those found for normal gait ■

VA RR&D CENTER HINES

EVALUATION OF AN ULTRASONIC DEVICE FOR GAIT ANALYSIS

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The objective of this study is to evaluate the effectiveness of a device developed at this VA center to provide objective data for gait analysis of neurologically and orthopedically involved patients. This information is clinically useful to define altered gait patterns due to abnormal muscle activity and the patient's progression in rehabilitation. The device was initially developed to monitor the walking patterns of blind pedestrians. It consists of two ultrasonic transmitters and receivers which provide a continuous measure of inter-ankle distance (IAD). Temporal gait phase relationships can be determined from the resultant graph of IAD versus time.

A portable electromyography amplifier has been developed and is used in conjunction with the ultrasonic limb-position monitor to record muscle activity in the involved limb during ambulation. To date, 40 normal volunteers and approximately 20 patients with hemiplegia have been studied.

The data providing both temporal gait phase relationships and dynamic muscle activity compare quite favorably with the accepted norms. This information has proved useful in directing treatment and evaluating effectiveness of treatment. Plans are now near completion to commercialize the entire system. In the pre-production model, patient encumbrance will be diminished, while protability and clinical applicability will be enhanced ■

NIHR REC

QUANTIFICATION OF MOBILITY PERFORMANCE FOR FUNCTIONAL ASSESSMENT, DIAGNOSIS, AND THERAPY OF NEUROMUSCULAR, SKELETAL, AND SYNOVIAL JOINT DYSFUNCTIONS

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This project is addressing quantitative measures of the state of the musculoskeletal system in question, in order to derive patient-specific predictive models which will permit simulation of the consequences of skeletal alteration such as osteotomy or total joint replacement and/or muscular alteration such as tendon shortening or lengthening or muscle substitution.

Realization of the surgical simulation system requires precise kinematic data acquisition, accurate estimation of dynamic joint torques and forces which requires patient-specific mass and inertial properties, musculoskeletal models of the relevant human anatomy and means for making them patient-specific, and, finally, computer graphics which present the relevant anatomy to the physician, in familiar form, and animation programs which provide for simulation of locomotion changes consequent to simulated interventions.

The kinematic data acquisition system of requisite accuracy, rapidity, and automaticity has been achieved in the M.I.T. "TRACK" software coupled to the Selspot optoelectronic camera system. In the M.I.T. Mobility Facility, TRACK is being used in normal and pathological gait studies for upper and lower limb prosthesis research, and in sports biomechanics investigations. Currently the TRACK program is being adapted to the Selspot II cameras, which have the potential of reducing the current translational accuracy of 1 mm to a quarter of that value and similarly improving the current 40-milliradian rotational accuracy. The Selspot II camera system also provides greater flexibility in trade off between number of active LEDs and frame rate, providing for acquisition frequencies as high as 10 kHz.

A recurrent and unresolved question in gait analysis is whether externally mounted markers are true indications of the actual limb segment, e.g., of bone kinematics. (Or to put it another way, what is the effect of skin and soft-tissue movement on the motion of such markers?) To explore that question, data has been acquired by the TRACK system from 3 LED configurations around the human knee under identical conditions of passive and active movement including gait.

Understanding normal and pathological locomotion patterns demands detailed knowledge of the time course and force activity levels in the individual muscles whose coordinated activity produces human movement. To address this need, an anatomically correct, detailed musculoskeletal model of the human lower limb has undergone successive improvement and evaluation in our Laboratory over the past several years.

For the latter study, a two-degree-of-freedom ankle manipulandum was designed and implemented. Under computer-control, electrohydraulic servo systems generated torque and position profiles with active tracking by the human subject as EMGs were measured using both skin and needle electrodes.

Just as the limb segment, mass, and inertial properties must be made patient-specific, the parameters of the musculoskeletal model must be adapted to the individual patient's anatomy. The CAT-scan digital graphics data, used for the inertial property analysis, is a potential source for specializing anatomical details such as muscle length and cross sections, origins and insertions, bone geometries, etc.

Calculations of joint forces and moments cannot reflect muscular forces arising due to co-contraction of synergistic muscles about the same joint, since the kinematic data which drives the dynamic calculation relfects only the net muscular torque about the joint from the synergistic muscles. To explore the role of co-contraction in normal and pathological movement, and to verify kinematic-based dynamic calculations of joint force during non-co-contraction movement, data from an instrumented femoral-head prosthesis will be employed. The pressure-instrumented endoprosthesis was developed primarily for synovial joint research and osteoarthritis. However, the integration of the pressure measurements from the 14 integral transducers in the pseudo-femoral head produces the load vector across the human hip. The comparison of this direct experimental measurement with the dynamic-force calculation derived from the kinematic data is therefore possible, and will serve to validate TRACK/NEWTON analyses and establish the level of co-contraction in various movement tasks.

Both the instrumented prosthesis and extensive excitation, calibration, real-time display, and recording apparatus are ready.

Future clinical use of the surgical simulation system mandates computer graphic displays of anatomy, and computer-animated simulation of patient locomotion following simulated surgery, which appear "realistic" to the physician. Preliminary work on animation has started, but considerably augmented computer capability and more sophisticated color graphic displays will be necessary to present static and dynamic information in a fashion compatible with the physician's prior experience ■

NIHR REC

QUANTIFICATION OF RESULTS OF RECONSTRUCTIVE SURGERY IN RHEUMATOID ARTHRITIS

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Introduction — Reconstructive surgery is performed to relieve pain and reduce the consequences of disability. Because recovery of normal function often cannot be attained, the patient's postoperative functional level must be assessed. Traditionally, functional assessment has been made descriptively and subjectively. For this reason, comparison of data from different centers has been of limited value. An in-house calculation of the correlation of descriptive ratings and direct gait measurements for 149 arthritis hip patients proved modest ($r = .62$ $p<.001$).

Evaluation of metatarsal head resection has been limited to operative descriptions. Measured function has focused on more able patients with lesser surgery such as bunionectomies.

Methodology — Four pre-operative rheumatoid patients (seven limbs) and five healthy individuals (nine limbs) were tested. Stride and foot support measurements were obtained with insole footswitches inserted into the patient's shoes. The insoles contain compression-closing sensors located in the area of the heel, first and fifth metatarsal heads, and great toe.

Center-of-pressure data were acquired by means of a Kistler force plate (placed in the center of the walkway) and Apple II + computer system (Fig. 1). Four vertical, two progressional and two mediolateral

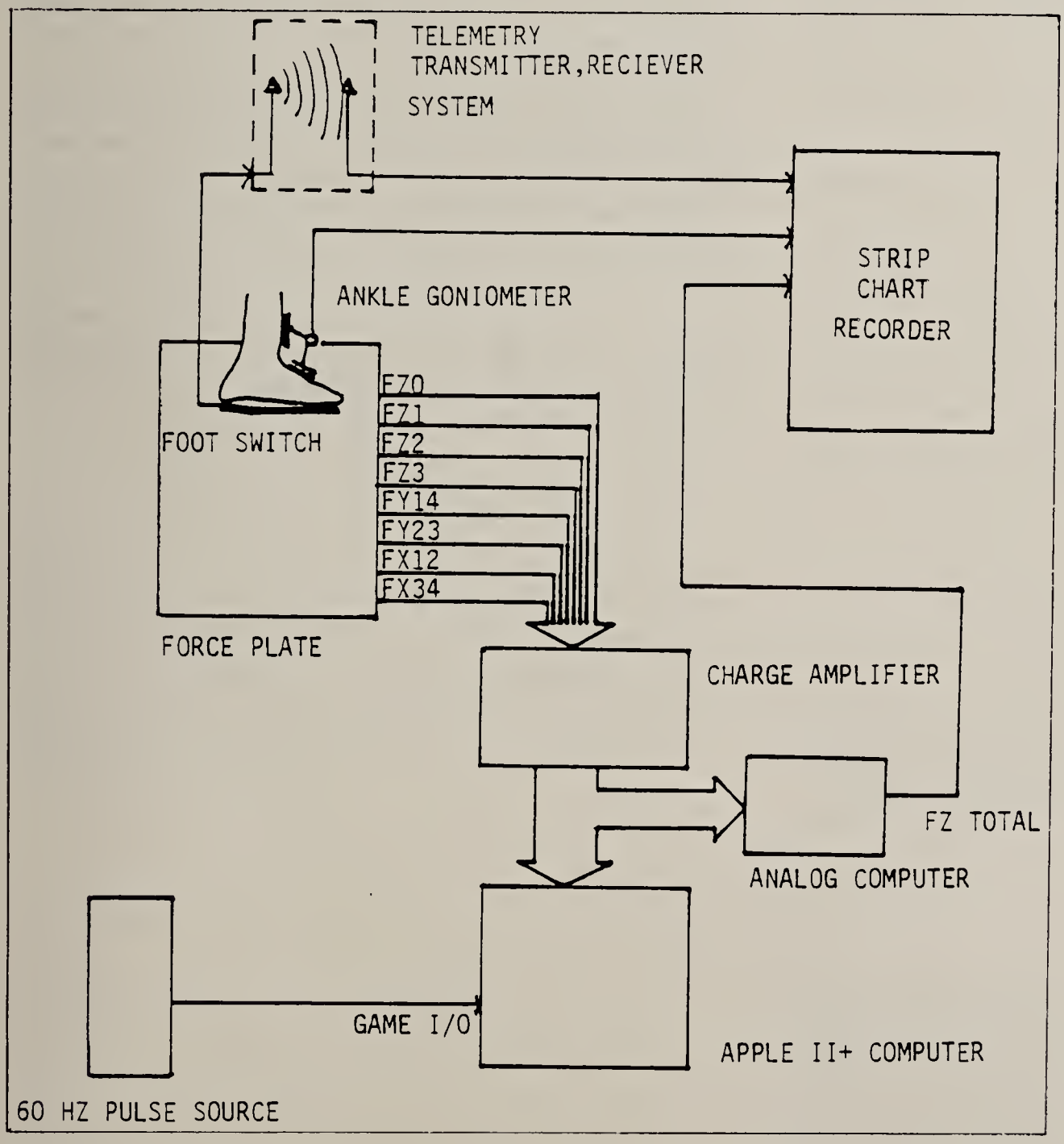

FIGURE 1.
Data acquisition block diagram for determination of center of pressure.

force component signals from the force plate were sampled by the computer at a rate of 60 Hz. Analog-to-digital conversion was accomplished by this system with a nominal accuracy of .098 pounds/bit. Data were stored on floppy disk.

Results—Three variables revealed that significant differences ($p<.01$) existed between the arthritic and the healthy groups. Single-limb support was initiated at 11.8 percent of the gait cycle in the healthy group compared to 21.7 percent for rheumatoid subjects. The rheumatoid group allowed the center of pressure under the foot to progress only half the distance to the metatarsal heads during single limb support. In contrast, progression in the healthy group was 131 percent of the functional weight-bearing area, well beyond the metatarsal heads. Finally, the maximum loading under the foot (expressed as a percentage of body weight) was 17 percent less for the rheumatoid group than the healthy group. Velocity and stride length averaged about 50 percent less than comparable data for normals, while single limb support times averaged 70 percent of normal ■

LOWER LIMB PROSTHETICS MISCELLANEOUS

NIH MUSCULOSKELETAL

HUMAN RESPONSE AND LOWER EXTREMITY INJURY

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Human injury is a complex process whereby external forces are transmitted to the human musculoskeletal system, the system responds in the manner of displacements and rotations, stresses are induced in the tissues, and under some conditions the tissues are disrupted. When the forces are not constant, prediction of the likelihood of injury and the severity of the forces is difficult. This project presents a research program investigating the mechanics of lower-extremity injury, specifically injuries to the knee, tibia, and ankle that typically occur in snow skiing.

Snow skiing is studied because the lower-extremity injury rate is high, because the forces transmitted to the foot can be measured, because response to the lower extremity can be measured, and because safety devices can reduce the high rate of injuries. Specialized laboratory and field test equipment have been developed to measure and analyze the forces between the boot and the ski, the rotations occurring at the ankle, knee, and pelvis, and the integrated EMG from muscle groups during skiing — and especially during falling when severe loading occurs and the likelihood of injury increases.

The field measurements identify the injury environment, and the laboratory experiments clarify how the lower extremity responds to dynamic loading. This is the "identification" problem for the lower extremity. The true severity of the typical skiing environment, and the contributions of the musculature in influencing the likelihood of injury will be clarified.

The common belief that the forces of skiing are small compared to typical tibia fracture strength and knee ligament strength will be tested. That belief is widespread, extending to standards organizations, the industry, and the public. If this is an error it is one which has major impact on the design of safety devices, on the evaluation and acceptance of safety devices, and on the training and instruction given the public. Efforts are directed to development of meaningful standards of safety ■

UPPER LIMB GENERAL

NIHR REC

QUANTIFICATION OF THE FUNCTIONAL CAPABILITIES OF UPPER EXTREMITY AMPUTEES

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The goal of this project is to develop a technique for quantification and measurement of the upper-limb functional capability of able and disabled persons. The technique being developed uses dynamic optimization theory to produce a single meaningful number derived from accessible measurements (such as myoelectric activity, speed, range of motion, etc.) and to provide an essential link between measured performance and inferred functional capability.

The next phase of this project is the experimental verification of the accuracy of that extended mathematical description of the maintenance of posture. To this end, state-of-the-art instrumentation for the real-time digital processing of myoelectric activity has been developed.

The processing technique is based on a mathematical model of surface myoelectric activity, from which the optimal (maximum likelihood) estimator of muscle force was derived. This optimal processor has been implemented, using digital microprocessor technology, and yields an order-of-magnitude improvement over conventional processing techniques. Experimental results indicate that muscle force can be estimated in 250 ms. with an RMS error about the mean of as little as 2 percent. A major advantage of digital microprocessor implementation is that the tedious but necessary calibration process is performed automatically ■

LIBERTY MUTUAL, NIHR, SWEDEN

THE MYOELECTRIC SIGNAL: DIFFERENCES DUE TO HANDEDNESS AND GENDER

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Previous work in our laboratory suggests that the initial median frequency of the myoelectric signal may be influenced by the handedness of an individual when comparing contralateral limbs. This observation resulted from tests on the first dorsal interosseous muscle of the hand in 15 right-handed subjects (10 male, 5 female) and 5 left-handed subjects (2 male, 3 female). Initial evaluation also indicated that female subjects appeared to have a higher initial median-frequency value than their male counterparts.

Additional experiments were conducted recently to effectively evaluate these results. The first dorsal interosseous muscle was tested in an additional 17 left-handed subjects (8 male, 9 female). Each subject was asked to isometrically abduct the index finger at various force levels and for different time durations. The force output and the signal were then recorded and subsequently analyzed using the Muscle Fatigue Monitor described previously.

Results from this experiment support our earlier findings that in left-handed subjects, no relationship was found between the initial median frequencies of the corresponding contralateral limb muscles. In right-handed subjects tested previously, however, the value of the initial median frequency did appear to be related to hand dominance. In this group of right-handers, the value of initial median frequency of the non-dominant hand was either equal to, or higher than, that of the corresponding muscle of the dominant hand at every level of contraction tested.

The relationship of hand dominance to initial median frequency may reflect changes in muscle fiber composition that results from the preferred use of the dominant hand over time. More direct measurements of muscle fiber types are necessary to verify these conclusions. The implication, however, for researchers and clinicians is clear: it may not always be appropriate to use the contralateral extremity as a reference when evaluating the affected limb.

Our recent findings, with regard to the relationship between gender and initial median frequency, contradict our earlier findings. No consistent differences in initial median frequency values appeared

when comparing male to female subjects. Further analysis, by pooling larger numbers of subjects tested, will be implemented to clarify this apparent contradiction in the data ■

MAXILLOFACIAL PROSTHETICS

VAMC WILMINGTON

MAXILLOFACIAL PROSTHETICS: TECHNIQUES AND CLINICAL APPLICATIONS

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Introduction — During the report period (Jan. 1, 1983–June 30, 1983) development and improvement of the human excised donor (HED) tissue culture technique was continued with the goal of providing a human-relevant affirmation of production lot quality control without dependence on long-term animal model testing. The HED test system, currently under review by the American Society for Testing and Materials (A.S.T.M.) Subcommittee on Medical and Surgical Devices, is at the stage of options in the use of specially and variably processed human serum targeted for specific cell metabolism and growth.

Attention is also being given to the use of PDM Siloxane in other areas of anatomical reconstruction which could potentially benefit from the high tear strength and elasticity of this material.

Product Development — A proposed guideline for the acceptance of PDM Siloxane for maxillofacial materials has been drafted and submitted to the American Dental Association and the American Academy of Maxillofacial Prosthetics.

The guidelines include four definitive requirements in conformity with the provisions of the Medical Devices Act on safe and effective medical and surgical materials and devices. The requirements, for the product and device acceptance, include appropriate standards in the areas of (i) generic chemical description, (ii) physical and mechanical properties, (iii) usefulness of product and (iv) evidence of safety.

Fabrication of prosthetic gloves — Because of its high tear resistance, up to threefold of that of skin tissue, along with flexibility, up to 800 percent elongation before tearing, and biocompatibility with human tissue, chemically defined PDM siloxane thus has the essential product attribute to replace polyvinylchloride (PVC) covering gloves for artificial hands.

Considering also its chemical resistance and resistance to light (which PVC cannot withstand beyond several months) its various features make the PDM siloxane a desirable substitute. As a consequence, consideration is being given to devising, (i) a fabrication system by the pressure molding technique in hardened stone and (ii) a new, modified fluid viscosity composition of PDM siloxane that would be adequately adapted to the latex dipping technique.

Pigmentation (internal shade stocks) — Cosmetic matching of prosthetic devices to duplicate the coloration of adjacent skin areas has not been accorded any official or authoritative reference standards. It is practised as an individual art, more often than not employing undefined colors, vehicle (thinner) diluents, and undefined (chemically) manufacturer's colorants, often derived from potentially toxic cadmium and lead pigments. In this project, a reference standard in terms of digital color difference indices is being included as an adjunct to the guidelines for acceptance described in previous section.

Toxicity-test procedure for biocompatibility — The present draft of the proposed ASTM Standard, using the HED tissue-culture testing system to affirm non-toxicity of PDM siloxane, provides several options employing processed human serum, in lieu of conventional animal, notably calf serum. The on-going effort involves developing a consequent series of specifications for standardized options in the use of processed human serum and its derived products.

The first option is the use of dialyzed human serum with the removal of toxicants at molecular exclusion by 3500 dalton membrane cut-off. However, the conventional usage of calf serum does not include its dialysis. The so dialyzed serum, along with the Holmes' A-3 chemically defined medium, is used to culture both established cell lines and primary cells for affirming the safe, non-toxic quality of production lots of PDM siloxane used for orofacial, reconstructive molded prostheses.

However, the current dialyzed human serum, even though appropriately specified and standardized in terms of dialysis, is obviously a human variable source, with undetermined cell growth and inhibitory factors. These molecular complexes include the lipids and lipoproteins that may be inhibitory or toxic in cell growth. On this account, two other options

are being developed to enhance the proposed ASTM standard with subsidiary human serum fraction standards.

The second option is the use of the Holmes' alpha-1-protein growth (AGF) factor, separates from the dialyzed human serum by glass bead chromatography. This second option has been consistently affirmed with an extensive series of human serum lots using established cell line, but has yet to be affirmed with human primary cells. The AGF is one of 7 to 8 protein factors separated by this chromatographic separation which have varying effects on the growth and morphology of test cells. In general, these factors appear as complexes with lipid structures which are suspect as cell-growth inhibitors and when used in culture give rise to variations in morphology of cultured cells. This of necessity imposes a need for delipidizing the dialyzed serum by gradient centrifugation in the presence of high-density medium.

The third option is the use of delipidized (using the same chromatographic separation) analogs of the second option. The delipidized growth factors are now under study for use with established cell lines and with primary cells.

In due course, the preference for one option or the other is expected to be determined by cell response most replicative of the mature, highly developed tissue cells.

Field (Clinical) Participation — PDM Siloxane has been provided to 56 VA and non-VA clinics having a participative interest in orofacial reconstruction. A technical service, consisting of color TV, video-cassettes, publications, workshop sessions, and presentations, has been provided.

Production — The project has produced 680 one-pound units of internally pigmented and non-pigmented PDM siloxane, distributed to over 50 VA and non-VA clinics. Units are monitored by test moldings from which the determination of tensile properties and tear resistance are determined in accordance with the mandatory provisions of the FDA Good Manufacturing Practices ■

Spinal Cord Injury R&D

In this section, under the broad heading of Spinal Cord Injury R&D, reports in the following general areas will be found: **Electrical Stimulation and Gait Analysis; Robotics; Mobility Aids** including **Wheelchairs, Wheelchair Accessories, Controllers and Lifts, Decubitus Ulcer/Seat Cushions, Automotive Adaptive Equipment; ADL and Recreation; Treatment and Training; Diagnostics and Information; Spinal Trauma, Musculoskeletal Rehabilitation; Information.**

ELECTRICAL STIMULATION AND GAIT ANALYSIS

LIBERTY MUTUAL, NIHR, SWEDEN

VOLUNTARY NERVE SIGNALS FROM PRIMATES

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In order to control additional degrees of freedom in our electromechanical prosthesis (the Boston Elbow) according to our concept of using control signals most directly related to the movement to be duplicated, neuroelectrical signals obtained from the severed nerves in the arm will be required. An elaborate experiment was initiated using a primate trained to perform movements duplicating two desired functions of the Boston Elbow. By using either wrist or finger movements, the primate was trained to track a computer-generated moving target. A juice reward was given for each correct response and the computer kept score of the results. After the training period was completed, two of our previously designed recording electrode units were successfully implanted in its arm around each of the two nerves controlling finger extension/flexion and wrist rotation. Both sensory and motor-nerve signals from wrist and finger motions were recorded while the primate performed the tracking tasks. The signals were processed and analyzed using a digital computer. The preliminary results indicate a correlation between the intended task and neuroelectric activity in each nerve ■

NIHR REC

RESTORATION OF UPPER LIMB FUNCTION THROUGH FES

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These studies are the core area of research in the center. The purpose of the project is to develop and evaluate systems employing functional electrical stimulation to provide control of hand movement. These studies are being performed in conjunction with the VA Rehabilitation Engineering R&D program, and the current status is detailed in a progress report that appears elsewhere in this issue ■

VAMC CLEVELAND

FUNCTIONAL NEUROMUSCULAR SYSTEMS FOR UPPER EXTREMITY CONTROL

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Part 1. Development of Upper Extremity Orthoses Employing Electrical Stimulation

A neuroprosthetic system has been developed to restore upper-extremity control through application of functional neuromuscular stimulation. This tech-

nique enables the C5 and C6 level quadriplegic to utilize his hand functionally.

System Description — Subjects with C5 or C6 level function are candidates for use of the system. Control of the system employs a voluntary command generated by the patient to activate coordinated movement of the hand. This voluntary command proportionally regulates the output of up to four channels of stimulation. The stimulus output of each channel is modulated according to a coordination algorithm determined in laboratory studies, to provide satisfactory motion for the set of muscles and electrodes employed in the particular individual.

System Implementation — Muscles to be stimulated are those which can be used to provide either a lateral prehension/release or palmar prehension/release and have the lower motor neuron intact. Generally eight or nine muscles are implanted, including the finger flexors (flexor digitorum superficialis and profundus), finger and thumb extensors (extensor digitorum communis and extensor pollicus longus), and thumb intrinsics (abductor pollicus brevis, flexor pollicus brevis, and adductor pollicus). These muscles are implanted with percutaneous coiled wire electrodes.

Portable Functional Electrical Stimulation System — A portable functional electrical stimulation system utilizing a microprocessor has been developed. Incorporation of the microprocessor has resulted in a user device which can be programmed to accept and process a variety of user-generated commands and to output complicated stimulus patterns. The availability of these enhanced stimulus regimes and more complex user-control algorithms enable us to tailor the device to a larger population of potential users.

System Use: The microprocessor-based portable electrical stimulation system has provided us with a functionally more powerful system than our earlier discrete logic systems. The advantages that are most evident are the simplicity in fabrication of each unit, the ease in establishing input control processing and output stimulation schemes, and the fact that each unit is identical and not patient-specified prior to the assembly of the device. With previous systems, much time was spent in hardware fabrication due to variations in the user control algorithm.

Patients' Use of Functional Stimulation System — Subjects are provided with the functional system for training and use. The use of the system is incorporated into the regular inpatient occupational therapy program. The occupational therapist and rehabilitation engineer jointly train the subject. Patients may be fitted with the system as soon as they are medically stable and ready to accept an assistive device.

Thirteen patients have been provided with the FES hand assist system.

Patients use the system for combing hair, brushing teeth, applying toothpaste to toothbrush, shaving with electric or safety razor, washing face and neck, eating and drinking, writing, and self-catheterization. The patient wears his neuroprosthesis throughout the day to have the flexibility of independently performing a functional task at his discretion.

The present system has had 344 user-months of evaluation. Some of the problems encountered include external cables (connecting electrodes and control transducer to the stimulator) which are encumbering, and percutaneous electrodes which require maintenance of the implant site. (To overcome these problems, we are presently developing an implantable stimulator.) However, despite these deficiencies, at the present level of development the FES system is sufficiently reliable and functional and it is, in general, prescribed and used as the primary functional orthosis for high level spinal injury patients at our Center.

Part 2. Implantable Systems for Stimulation of Skeletal Muscle

An implantable muscle stimulator has been developed using semi-custom integrated circuit technology. The unit is reliable, small, lightweight, has low power consumption, allows freedom of movement, and is intended for permanent usage.

The stimulator circuitry is externally controlled and powered by a single encoded radio-frequency powering carrier. Up to eight independently controlled stimulus output channels are provided, with the output channel selection, stimulus pulse width, and stimulus pulse frequency all under external control. A constant-current biphasic stimulus pulse is used, in which the stimulus current amplitude can be programmed by a single resistor value. The stimulator circuitry has been implemented in thick film hybrid form, and has been undergoing laboratory evaluation for 16 months.

The stimulator circuitry has been encapsulated in glass-ceramic packages for use with long-term animal evaluation. Hermetically sealed titanium packaging, suitable for implantation in human subjects, is currently being developed. Stimulating electrodes have been developed that are mechanically reliable and provide stable stimulus characteristics.

Both laboratory testing and animal evaluation have been performed. In vitro studies are ongoing to

determine the responses of the electrodes to extended periods of stimulation. Animal evaluation has been used to address the overall system performance; stimulators have been operational in animals for more than 10 months.

The development of this system consists of three main areas; electronics, packaging, and stimulation electrodes ■

VA RR&D CENTER PALO ALTO

NEUROMUSCULAR MODELS WITH APPLICATION TO REHABILITATION AND TO FES OF PARALYZED MUSCLES

VA Rehabilitation Research and Development Center
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■ Participants in the Neuromuscular Model project were the following:

From the Rehabilitation R&D Center, PAVAMC: **Felix E. Zajac, Ph. D.**, and **Michael R. Zomlefer, Ph. D.**

From the Department of Electrical Engineering, University of Maryland: **William S. Levine, Ph. D.**, and **Jean-Pol Chapelier.**

Need — Spinal cord injured persons and others with severe motor disabilities need to regain use of their extremities.

Our knowledge of how the CNS coordinates muscles and how this array of muscle action affects motion of the limbs and the interaction of the limbs with the environment is scant.

Approach — Motor control physiologists studying body motion have focused on understanding single-joint movement using EMG, kinesiological, single unit and in vivo force recordings. Except for descriptions of the neuromuscular events correlated with the movement under study, these studies have resulted in few predictive theories for motor control. On the other hand, biomechanicians have studied movement by computing joint torques and forces from measurements of body motion using as a basis dynamical models of multi-jointed structures. While such studies have been fruitful, particularly in the design of artificial joints, they have had limited success in enhancing our knowledge of intermuscular coordination.

Analytical and computational models of the neuromuscular system can be used to understand the role of tendon elasticity and muscle strength, elasticity, speed, and coordination on body movement. Optimization theory applied to neuromuscular control has the potential to define the pattern by which single muscles ought to be coordinated for the body to achieve a specific motor task. Critical to these models is a representation of muscle that uses the fundamental properties of muscle as a basis, and yet is simple enough for computer implementation.

We chose an approach to muscle modeling that is robust. It purports that generic to skeletal muscle and tendon is architecture (i.e., the geometric composition of sarcomeres and the geometric relationship of muscle to tendon) and sarcomere dynamics. The approach assumes that one model will differ in complexity from another primarily because the sarcomere properties deemed important to understand one motor behavior may differ from those of the other. Tendon properties and origin-insertion geometry are included, since we are interested in assessing how energy storage mechanisms in tendon and muscle contribute to human movement.

Status — At the moment we are using this model to study the quadriceps muscle. We find that computed isometric torque-angle and isokinetic torque-velocity curves are similar to those obtained by subjects exercising in a Cybex instrument. We are exploring ways to use data collected non-invasively in the clinic to estimate tendon and muscle properties of the rectis femoris and vasti groups (e.g., the number of sarcomeres in the muscle fibers, the physiological cross-sectional area of each muscle group, and tendon elasticity).

Development of a more complex neuromuscular model of lower limbs is planned. The model will be developed to assist in gaining an understanding of how sensitive standing and walking are to muscle strength, elasticity, coordination, and other factors. This approach can be used to suggest optimal strategies of muscular coordination needed to restore standing and walking in the spinal cord injured person via functional electrical stimulation ■

VA RR&D CENTER PALO ALTO

UTILIZATION OF SOMATOSENSORY SIGNALS IN THE GUIDANCE OF VOLUNTARY MOVEMENT

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Need — Disease or injury of the nervous system often results in a loss of the somatosensory information requisite for the execution of skilled motor performances. This consequence extends to the use by individuals of myoelectrically controlled pros-

theses or electrically activated musculature, where visual feedback remains the sole means of performance monitoring. Unfortunately, we have comparatively little understanding of how somatosensory cues enter into voluntary movement programming — and we will need this knowledge both to understand sensorimotor dysfunction and to develop effective restorative measures.

Approach — On the basis of earlier studies, we have hypothesized that the CNS interprets somatosensory cues differently during movement than it does during quiescence. Such movement-related alterations in processing should be detectable in a variety of ways, among them:

1. Changes in the electromyographic (EMG) properties of short-latency reflexes evoked by somatosensory inputs;
2. Changes in the properties of cortical somatosensory evoked potentials (SEPs) triggered by those inputs; and
3. Changes in the conscious perception or interpretation of somatosensory cues.

We have explored all of these possibilities using techniques in which the EMG, SEP, and perceptual consequences of sudden movement perturbations are recorded in human subjects attempting to perform prescribed motor activities with forearm, wrist, or index finger.

Status — The character of voluntary motor effort has indeed proved material in prescribing CNS reactions to somatosensory input. Thus, for example, we have found that the "normal" Sherringtonian reciprocal reflex linkage between antagonistic muscle pairs can be "reversed" into a co-active relationship when the CNS voluntarily uses such muscles against nonskeletal, external loads. We have also observed that brief perturbations of joint position during voluntary activity are neither correctly perceived, nor capable of SEP production — even though the same perturbations generate both potent SEPs and proper perceptual reports during motor quiescence. It thus seems quite clear to us that any scheme for utilizing somatosensory feedback to improve prosthetic or "natural" motor skills will require more than just the literal transduction of physical signals (position, force, velocity, etc.). Provision must also be made to identify those times during a motor performance when the CNS is best capable of making use of such data.

Pending — Our present aim is to characterize quantitatively the relationship between voluntary motor effort and changes in somatosensory processing. To date, for example, we have demonstrated a nearly linear relationship between the amplitude of SEPs evoked by movement perturbations and the error rates of subjects attempting to identify certain perturbation properties. A similar relationship may hold between SEP amplitude and the rate of force alterations (both increases and decreases) in an isometric motor task. We also anticipate further studies in which we attempt to characterize the voluntary "intent" of moving subjects by identifying those variables of movement (e.g., EMG, force, directionality, etc.) that appear to be most closely regulated ■

NIHR REC

SENSORY SUBSTITUTION USING ELECTROCUTANEOUS STIMULATION

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The objective of this project is to develop feedback devices that will provide information about grasp force and extent of hand opening to persons having asensory hands. The intended users will mainly be upper-limb amputees who are fitted with myoelectric terminal devices, and C5 and C6 level spinal injury patients who are using functional neuromuscular stimulation systems to achieve functional grasp.

Electrodes — The subdermal electrodes that are initially being evaluated are made of tightly coiled, fine stainless steel wire, similar to those developed by Caldwell and Reswick.

The electrodes have been allowed to remain in place for many months. A cumulative total of 16 electrodes have been implanted in seven adult male subjects.

Stimulus Parameters — Stimuli consisted of monophasic, capacitively coupled, rectangular pulses presented either as single pulses or bursts. For the case of subdermal stimulation, a constant-current source was used, but when the skin was stimulated using surface electrodes, a constant-voltage source was employed. Pulse widths of 10–100 microseconds have been tried and these consistently elicited clear, distinctive sensations reported as having a "tapping" or a vibratory quality (depending on the stimulus frequency) which was localized to the electrode site.

Threshold Stability — Thresholds for electrocutaneous sensation using identical subdermal electrodes are found to require levels of current in

the range of 0.3-6.0 milliamperes (ma), the level seems to depend upon conditions for each individual electrode and becomes apparent only after it has been installed.

The distribution of the threshold currents for 16 electrodes at approximately 7 days following implantation is shown in Figure 1. The thresholds range from 0.3 to 6.0 ma with a mean of 1.4 ma. For 8 of these electrodes that were studied for at least 30 days, the mean current was 1.2 ma at day 7 and this value was unchanged at day 30. These data indicate that the electrodes retain their ability to stimulate the skin within reasonable limits of current. Mechanical stability of the electrodes within the tissues appears to be adequate.

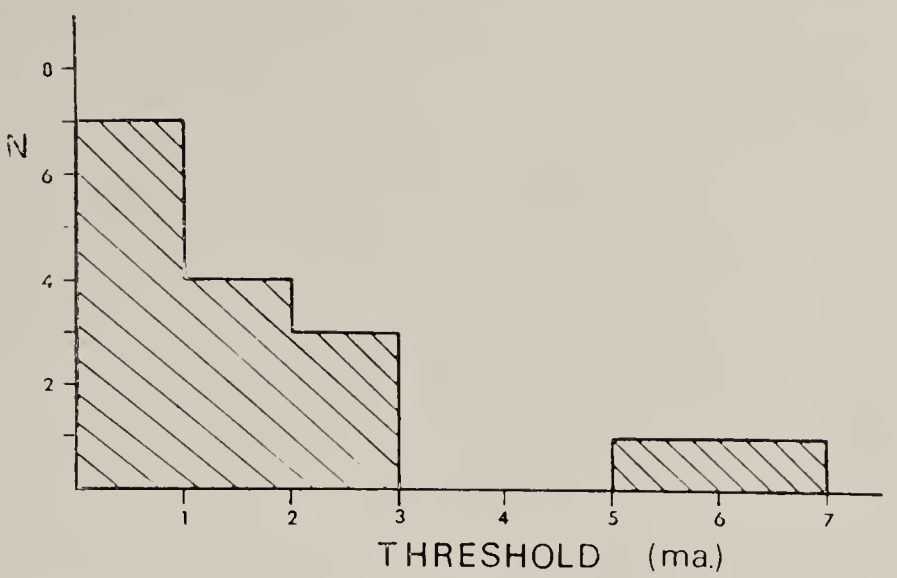

FIGURE 1
Distribution of threshold current for subdermal electrodes.

Dynamic Operational Range — A considerable variation in dynamic ratio has been found among the several electrodes that have been installed. Since the geometry of the electrodes themselves was carefully controlled, we attribute their performance variability to our inability to position them under the skin at identical depths and with identical proximity to the neural elements that the electrical stimuli excite. A further source of variability in the dynamic ratio derives from each individual's subjective impression of the level of discomfort that constitutes an unacceptable electrocutaneous sensation. It should be pointed out, however, that in the same individual, one electrode installation may feel very "good", in terms of its ability to induce clear, distinct, and comfortable sensations, while another electrode which is placed in the same skin region under apparently identical conditions, might have less favorable qualities.

Fortunately, the performance characteristics of each electrode after it was installed remained consistent over the course of weeks or months that each was studied. A particularly "good" electrode thus remained so. In a few cases, electrodes that initially induced less comfortable sensations improved with "aging". This latter effect may coincide with the development of a fibrous tissue sheath about the electrodes during the process of encapsulation.

Accommodation and the Choice of Sensory Codes — The effects of accommodation would be expected to be particularly troublesome where intensity-modulation sensory codes are to be employed, because the accommodation manifests itself as a decrease in the subjective magnitude of the stimulus intensity. For the case of a tactile substitution device in which information about grasp force is to be provided, if the stimulation is only given during the actual act of grasping an object and is turned off after the object is released, the skin area receiving the stimulation will be in a constantly changing state of accommodation and recovery from accommodation. This difficulty can be minimized by employing a frequency-modulation code to signal the level of grasp force, since the fidelity of the frequency code should be less dependent on accommodation effects. For this reason, our efforts have been largely directed towards the development of a suitable frequency-modulation code, which will be discussed below.

Just Noticeable Differences of Frequency — JNDs of increases in frequency were determined over a range of 2-100 Hz for several subjects, in order to determine the usable range and the theoretical resolution that would be available if grasp force was encoded by an electrocutaneous frequency-modulation code. A psychophysical technique, the "Dual Staircase Method" was implemented in a computer-assisted algorithm and used to obtain data.

Figure 2 shows the results that were obtained with one well practiced subject, using subdermal stimulation versus more conventional surface stimulation.

The significance of our findings is that the use of a subdermal electrode for stimulating the skin allowed the subject to discriminate at least 15 JNDs of frequency in the range of 2-55 Hz, whereas only 11 JNDs could be discriminated when a surface electrode was employed.

The superior performance of the subjects when the subdermal stimulation was employed versus surface stimulation was verified in another experiment, in which three subjects were tested for JND values at six standard frequencies (2, 5, 10, 20, 30, and 50 Hz). Twelve experiments in all were conducted on each of the three subjects. There were two electrode locations and two types of electrodes at each location (i.e., two implanted subdermally

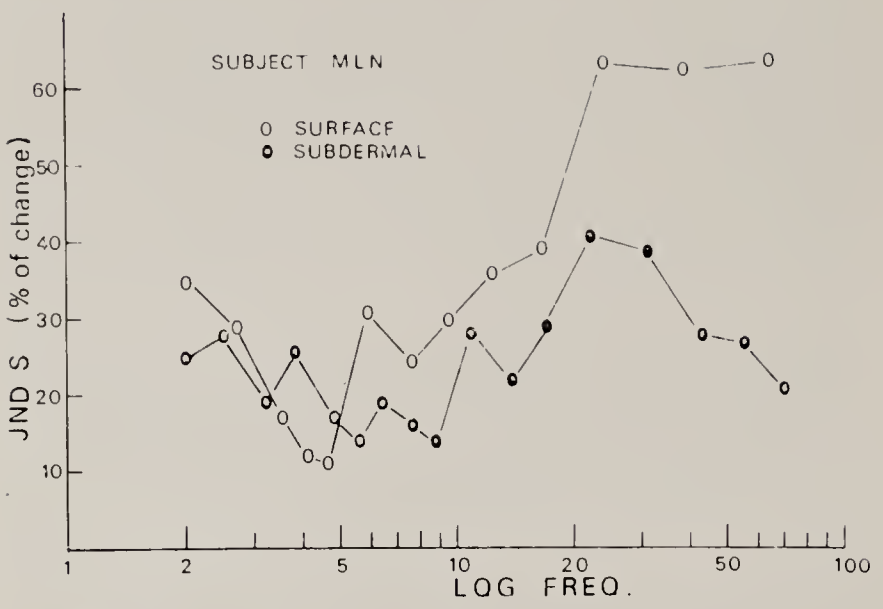

FIGURE 2
Successive JNDs of frequency using subdermal versus surface electrocutaneous stimulation.

and two that could be fixed onto the skin surface just over each subdermal electrode). Three independent evaluations of the JND tests for each electrode type/location pair were performed.

The data indicate that, for frequencies that are beyond 20 Hz, the subjects were able to discriminate smaller changes in frequency when the stimuli were presented with subdermal electrodes as compared to when surface electrodes were used. When the averages for the JNDs (expressed as percent change of frequency) were compiled separately for the subdermal electrodes and for the surface electrodes of each of the three subjects, the JNDs of frequency from 2–100 Hz were found to be on the average lower for the subdermal electrodes than for the surface electrodes by 25 percent, 10 percent and 23 percent, respectively, for the three subjects.

Choice of Stimulus Parameters — Subjects have consistently noted that stimuli which consist of bursts of high frequency pulses feel more comfortable than do single isolated pulses. A comparative evaluation of subjects' performance of a tracking task was conducted, using a frequency-modulation code in which the repetition rate of a burst of pulses (each burst consisting of 6 pulses of 50 microseconds duration and interpulse interval of 1 microsecond) versus a frequency modulation code in which the repetition rate of a single 50-microsecond pulse was modulated. A series of stepwise changes in frequency (each step consisted of a 2 JND change) covering a range of approximately 2–40 Hz was presented to the subject whose task was to detect each of the frequency changes. Preliminary results reveal that single-pulse codes are superior to burst codes if the frequency changes are centered at relatively high frequencies, but they are poorly discriminated at lower frequencies. Conversely, bursts of pulses afford more easily discriminated frequency changes when the frequencies are low, but are not clear at higher frequencies. A superior frequency-modulation code results when the number of pulses in each burst is made to vary with the burst-repetition-frequency presented ■

VA RR&D CENTER HINES

INVOLVEMENT OF MULTIPLE CORTICAL AREAS IN TACTILE SENSATIONS

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in collaboration with

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It is now generally accepted that certain neurological functions, especially those dealing directly with sensory input or with muscle control, can be ascribed to rather localized areas of the brain. When a stroke affects one of these cortical areas, a characteristic loss of sensation specific to one sense (such as touch) occurs with little or no loss to the others.

One of the aims of rehabilitation is to attempt to restore the function of the lost sense. However, so little is known about how the brain processes neuronal signals in a normal case — let alone in an injured brain — that many of the rehabilitative procedures are based on pragmatic and historical concepts. If we had a more precise understanding of brain function, we might be able to predict what sorts of deficits might be seen after a specific lesion, and whether we might be able to structure the rehabilitation process to enhance any residual capacity.

We have been using cats to study how the various portions of the brain that deal with the sense of touch interact. There are two main cortical regions (per each half of the brain) that deal with the sense of touch. They are known as the somatosensory areas and are heavily interconnected. They serve as the first cortical relays for touch sensation as it is processed and passed onward to other areas of the brain (for instance, to the motor cortex). We are beginning to study how the neural activity evoked in the two somatosensory areas by skin touch is patterned, and how the activity in one of these regions changes when the other is temporarily inactivated by topical injection of a local anesthetic. By being

able selectively to inactivate a small portion of the brain, we are hopefully able to produce an animal model for reversible stroke ■

NIHR REC

EFFECT OF STIMULATION PULSE DURATION ON COMFORT IN CONTROLLED MOTOR CONTRACTIONS

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Introduction — Studies conducted at this institution and elsewhere have shown that stimulus waveform can significantly affect the comfort of transcutaneous electrical stimulation. One stimulation parameter that is highly significant is pulse duration. However, none of the studies reported in the literature have reported objective assessment of the range of pulse duration that should be used to minimize discomfort.

A study involving 12 volunteer subjects was conducted to determine the most comfortable range of pulse duration between 12 and 800 microseconds (μs). The study also provided information as to how much more torque could be produced by the preferred pulse duration than was possible with less preferred pulse durations, thereby demonstrating the relative importance pulse duration has on comfort.

Comparisons of pulse durations were conducted at amplitudes resulting in the same physiologic response of torque generation. In order to better control factors influencing the assessment of comfort, and to reduce testing time, a computer-controlled microprocessor-based stimulator was designed and built to control automatically the electrical stimulation of subjects and the collection and analysis of data.

Methodology — A DEC MINC-11/23 computer was the host controller of the data collection and analysis procedure. It communicated with a microprocessor-based stimulator in controlling the stimulation and in retrieving subject data. The stimulator output current was directly proportional to a control voltage supplied by a 12-bit digital-to-analog converter providing a resolution of 1 in 4096. The stimulator output waveforms were controlled by a programmable timer which generated biphasic rectangular current-regulated pulses with variable duration with a resolution of one microsecond (Fig. 1).

Twelve subjects, all female, participated in this study. Four sessions, each conducted on a separate day, were used to establish a preferred comfort range for pulse durations of 12–800 μs and to assess how much more torque could be generated using a pulse duration that was preferred over one that was not preferred.

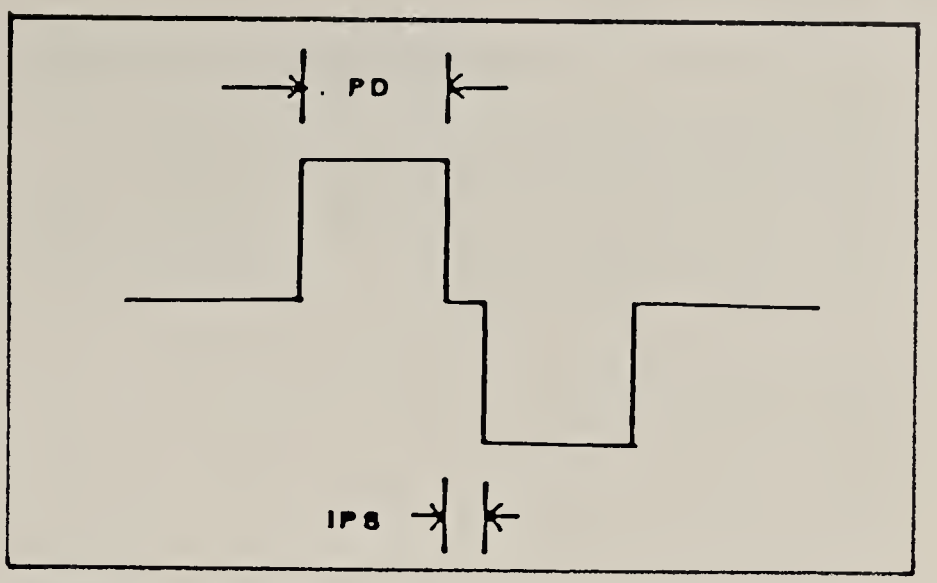

FIGURE 1.
Symmetrical biphasic waveform. PD = pulse duration (10 μs ⩽ PD ⩽ 1000 μs) and IPS = interphase separation (IPS = 25 μs).

Results — Ten female subjects completed the entire 4 day testing protocol. From the 5 runs with the least variance of torque in Session 2, subjects ranked their pulse-duration preference. The longest pulse duration, 800μs, was chosen 19 times, 300 μs was chosen 14 times, 100 μs 11 times, 30 μs 5 times, and 12 μs 1 time.

Torque Comparisons — Those whose preferred pulse duration was 300 μs and least preferred pulse duration was 12 μs tolerated an average of 211 percent greater torque when using 300 μs than when using 12 μs.

Comparing 300 μs to 800 μs, the six subjects who preferred 300 μs tolerated an average of 77 percent greater torque when using 300 μs than when using 800 μs. The three subjects who preferred 800 μs tolerated an average of 26 percent greater torque when using 800 μs than when using 300 μs.

This study demonstrates that a significantly greater amount of torque (211 percent) can be generated in the quadriceps when a 300-μs pulse duration is used, compared to torque generated using short pulse durations. Although three subjects preferred 800 μs to 300 μs, the torque differences were not significant. Consequently 300 μs was considered to be the overall preferred pulse duration ■

LIBERTY MUTUAL, NIHR, SWEDEN

DECOMPOSITION OF THE MYOELECTRIC SIGNAL

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The central nervous system controls muscle force by acting on the motor unit, a group of muscle fibers innervated by one nerve fiber, which forms the functional building block of the muscle. The activity of motor units can be studied by analyzing the electrical signal originating from the muscle fibers (the myoelectric signal), which can be detected by an electrode inserted in a contracting muscle. This is possible because each motor unit may be identified by its particular waveform in the myoelectric signal.

A system has been developed in our laboratory to examine the motor control of concurrently active motor units. This system consists of a means of recording myoelectric signals from needle electrodes implanted in a muscle, digitizing the information, preprocessing the information to improve the signal quality, running a sophisticated computer program to separate the individual motor unit firings from the total myoelectric signal, and then running other computer programs to combine and analyze the data. We have consistently striven to improve its performance, ease of use, and applicability to different experiments.

The myoelectric signal acquisition has been automated to increase the reliability of the data collected and the speed at which data are acquired. A minicomputer (PDP-11/34) is currently used as experiment controller. Under the directions of the operator, the computer controls the position of the tape recorder which stores the detected signals, monitors data quality, provides instructions and tasks for the subject of the experiment, and compiles a tabulation of all the operations performed during an experiment.

The newly developed multichannel recording electrode described above allows simultaneous recording of three independent differential channels of myoelectric signals. (The electrode previously used provided only two independent channels.) The addition of one independent channel of information reduces the data processing time by facilitating recognition of the motor unit action potentials in the recorded signal.

These improvements have greatly increased the ease of use and reliability of the decomposition system and have significantly reduced the time required to run an experiment and to analyze the data. This new tool will allow us to perform various types of experiments that were previously impossible to perform. It further enables us to perform them in numbers previously impossible ■

LIBERTY MUTUAL, NIHR, SWEDEN

HOW INDIVIDUAL MUSCLES ARE CONTROLLED: RELATIONSHIP BETWEEN FIRING RATE AND RECRUITMENT OF MOTOR UNITS

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The central nervous system controls the force being generated by a muscle by either varying (recruiting) the number of muscle fibers (motor units) that contract or by varying the rate (firing rate) at which they are stimulated to contract.

We have pursued our work in the investigation of control muscles as detailed in the two papers by De Luca et al. in J. Physiol., 1982. In those two papers, it was shown that different muscles utilize recruitment of motor units and increase the firing rates of motor units to different degrees when muscle force is to be increased. The present work is aimed at studying the effect of the recruiting of a motor unit on the firing rate of other previously activated motor units. Data was collected from the tibialis anterior muscles in the leg and the first dorsal interosseous muscles in the hand of three subjects.

In all records from the tibialis anterior muscle, we have observed an inhibitory effect of recruiting a new motor unit on the firing rate of previously activated motor units. In the first dorsal interosseous muscle, which primarily uses rate coding of its force output, the same effect has been observed, although not as consistently as in the tibialis anterior muscle. To our knowledge, this is the first time that a direct linkage has been demonstrated in these two mechanisms which regulate muscle contractions. The

functional significance of this interplay between recruitment and firing rate in a muscle is that smooth control of muscle output can be achieved by a local, hard-wired computing circuitry, thus sparing the central nervous system resources ■

LIBERTY MUTUAL, NIHR, SWEDEN

HOW INDIVIDUAL MUSCLES ARE CONTROLLED: STATISTICS OF MOTOR UNIT DISCHARGES

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The data from previous experiments was analyzed to look at the statistics of motor unit discharges during various muscle contractions. In these previous experiments, bipolar needle electrodes inserted in a subject's muscle were used to record the myoelectric signal produced when the subject maintained a contraction at a constant force level. The signals were then decomposed (according to the technique described elsewhere) to yield the firing times of several concurrently active motor units in the muscle.

The study involved the analysis of the power spectrum estimates of the firing rate of motor unit discharges. This was an attempt to investigate the presence of a low-frequency (approximately 1.5 Hz) modulation in the firing rate of the motor units noted during our previous studies. A computer program was used to convert firing time information into a train of unit impulses spaced at the appropriate firing times. This was then high-pass filtered to remove the DC component of the firing rate, Fourier transformed, and processed to yield an estimate of the power spectrum. This estimate was then smoothed by a low-pass filter to yield a lower variance estimate of the power spectrum. Power spectra for several different motor units of one contraction were then averaged to see if a peak corresponding to a common low-frequency oscillation could be obtained. The results revealed that a statistically significant peak could be found in only a few cases, suggesting that the common low-frequency oscillation seen in the firing rates of motor units cannot be modeled by a steady oscillation in the motor output. However, further analysis did reveal that the firing rate statistics of the motor units had negligible effect on the power density spectrum of a myoelectric signal which consists of the electrical signal from at least six motor units ■

LIBERTY MUTUAL, NIHR, SWEDEN

INTERACTION OF MUSCLES DURING CONTRACTIONS

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This study is directed at clarifying the role of agonist and antagonist muscle interaction during muscle contractions and initiation of movement.

The myoelectric signal from two forearm muscles (flexor pollicis longus and extensor pollicis longus) is acquired using the technique described in the project report on the Decomposition of the Myoelectric Signal (page 52). These two muscles are the sole effectors of the distal joint of the thumb. During an experiment, the subject is required to perform several tasks while the myoelectric signal is recorded. The original experimental protocol has been extensively modified following indications derived from pilot experiments. Such modifications include tracking of predictable and unpredictable trajectories and voluntary co-contractions of the two muscles that do not actually produce a net torque output at the joint. The purpose of the above tasks is to relate the firing rate behavior of the motor units in antagonist muscle under various working conditions.

Using the new protocol, three partially successful experiments have been performed. (The experimental difficulties encountered were the primary factors that promoted a wide revision of the data acquisition and processing technique as described in the project report on Decomposition of the Myoelectric Signal.) The current data has begun to show rather interesting aspects of the interaction of the opposing muscles ■

VA RR&D CENTER PALO ALTO

A STATIONARY BICYCLE ERGOMETER TO STUDY INTERLIMB COORDINATION OF HUMAN LEGS

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Need — It is necessary to understand interlimb coordination in order to develop rehabilitation strategies for persons with gait disturbances.

Disturbances in gait can be due to disturbances in balance, interlimb coordination, or both.

To reduce the level of conscious awareness needed to control a complex motor task, the CNS has developed strategies such that only a few, rather than many, parameters are needed to control the movement. In locomotion, for example, the basic pattern of alternation of flexor and extensor activity and interlimb timing may be generated at the spinal level with hierarchical supervision effected through supraspinal channels. However, in biped locomotion, balance is probably as important to locomotion as alternate movement of the legs.

Approach — To assess whether disturbances in gait are from disturbances in balance or interlimb coordination, an apparatus is needed so that interlimb coordination can be studied alone without the influence of balance.

Status — We have designed and built a prototype stationary bicycle ergometer with unique features. The features are that the two pedals can be placed at a range of phase relationships spanning 0 to 360 degrees and so that the two legs can pedal at different speeds.

Pending — This apparatus will let us assess whether this approach can be used to elucidate pathological interlimb coordination mechanisms in persons with a variety of neurological and musculoskeletal disabilities ■

NIHR REC

TRUNK EMG, VECTOR, AND GAIT ANALYSIS OF PATIENTS WITH INCOMPLETE S.C.I.

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The purpose of this study was to determine the extent to which the trunk and upper limbs are used in spinal cord injury patients for balance and support.

Method — Eight male incomplete spinal cord injury patients between the ages of 19 and 35 (mean 26.4 years) have been tested. There were three cervical, two thoracic, and three lumbar injuries. All were traumatic injuries resulting from motor vehicle accidents (three), gunshot wounds (four), or fall (one) within the past 18 months.

Two patients in the cervical group had bilateral AFOs. The third used a single AFO. One thoracic patient had no lower limb orthoses, while the other had an AFO/KAFO. Each of the lumbar patients had different orthoses (bilateral AFOs, AFO/KAFO, bilateral KAFOs).

Trunk muscle function during ambulation was recorded by placing paired 50-micron wire electrodes bilaterally in the upper (L_1) and lower (L_4) paraspinus muscles, the external oblique, and rectus abdominus. Crutches instrumented with force transducers measured arm assistance. Knee and ankle motion were recorded with electrogoniometers. Velocity, stride length, cadence, and the single and double limb support patterns were obtained by walking the subject over a known 6-meter walkway while wearing footswitches. A ground reaction force vector was obtained from a concealed force plate in the walkway; this vector was superimposed on the image of the subject ambulating by means of split-beam photography. Torques about the hip, knee, and ankle joints were calculated from the height of this vector times its perpendicular distance from the joint. The resultant value was divided by body weight times leg length, for patient-to-patient standardization.

Results

Walking Aids: In the cervical spinal injury group, one patient walked without crutches, another used a roll walker for balance and the third used crutches applying 6–8 lb of force. Among the patients with thoracic injuries, one used a single crutch (40 lb) and the other relied on two crutches, exerting 20 lb per crutch. The physiologic ambulator in the lumbar group used two crutches (60 and 45 lb). Of the other

two patients, two crutches were used on one (40 and 15 lb) and the other person used one crutch, exerting 45 lb.

Stride Characteristics: Seven of the eight patients were classified as household ambulators having a gait velocity of 30-60 meters/minute. The eighth patient was classified as a physiological ambulator with a gait velocity of less than 30 meters/minute. With the exception of the physiological amublator, there were no significant differences in velocity or foot-support patterns between the groups.

Abdominal Muscle Action: The rectus abdominus was not used by the cervical group, while this muscle was active unilaterally in one thoracic level patient. All of the lumbar group used the rectus at 50 percent of maximum intensity.

With the exception of the physiologic ambulator, the cervical group had the greatest number of muscle groups demonstrating spastic or continuous activity, which was followed by the thoracic group. This latter group had no activity in 50 percent of the external oblique muscles tested. The lumbar group had little spasticity and no muscle groups showing continuous activity.

The lower erector spinae muscle was generally most active during ipsilateral heel strike. The upper erector spinae, external oblique, and rectus abdominus worked roughly together during ipsilateral terminal stance to mid-swing ■

NIH MUSCULOSKELETAL

LOCOMOTION, MUSCLE FUNCTION AND METABOLISM

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This project has three main objectives:

1. To determine the manner in which muscles and populations of fibers within muscles are recruited and used during locomotion as animals increase speed and change gaits.
2. To investigate the relationship between muscular activity and the upper and lower limits of metabolism.
3. To test the hypothesis that the structural elements of muscle are quantitatively matched to functional needs.

A "force platform-film analysis technique" will be employed to: (i) correlate cross-sectional area of muscle groups that are active (as determined using a "glycogen loss technique") with the forces generated by these muscles; (ii) compare the active fraction of the total cross-section of muscle groups at gait transitions and during peak accelerations in animals of different size; and (iii) test and refine the hypothesis that the intrinsic velocity of shortening of the active muscle fibers is a major determinant of the energetic cost of locomotion.

The physiological parameters will be measured that determine the flow of oxygen from the capillaries of the active muscle fibers to the mitochondria and of ATP from the mitochondria to the cross bridges, under the limiting conditions of maximum oxygen uptake. Morphometric measurements will be made to quantify the spatial relationships between mitochondrial membranes, capillaries, and cross bridges of muscle fibers in major locomotory muscles of animals having very different aerobic capacities and intrinsic velocities of shortening. Then, an attempt will be made to match the physiological and morphometric measurements ■

NIHR REC

EVALUATION OF ABNORMAL MOTOR CONTROL

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The objective of these studies is to measure quantitatively the mechanical and neural components of the response to joint-angle disturbances interjected during maintained voluntary contractions. The first step in this process was to characterize the response properties in normal subjects, with particular regard to the dependence of responses on the magnitude and direction of the disturbance and on the initial torque and angle prior to the disturbance. In subsequent studies, the same measurements, in patients with movement disorders such as spasticity, will reveal whether alterations in the regulatory properties of the stretch reflex are present under pathological conditions.

In the time since the last progress report, the modifications to the equipment and software that were required to enable the study of regulated position disturbances (as opposed to the regulated torque disturbances that were studied previously) were completed. The modification made it possible to separate the dependencies of stiffness on angular disturbance size from the dependence on initial torque. It also made it possible to measure the passive component of stiffness, and by subtraction from the total stiffness, the active component of stiffness.

Stretch reflexes were studied at the interphalangeal joint of the thumb in adult normal subjects. Torque, joint angle, and electromyographic activity of the

flexor pollicus longus muscle were measured.

The responses to equal-but-opposite disturbances were approximately symmetrical, indicating nearly equal stiffness regardless of the direction of the disturbance. The electromyographic responses under these conditions were not symmetrical, but were indicative of a much larger reflex response to stretch than to shortening. These findings are in agreement with previous studies in stretch reflexes in human biceps and in decerebrate cat soleus muscles, where it was postulated that the reflexes compensated for the opposite nonlinearity of muscle response to stretch.

The increment in torque (angle) in response to a disturbance of angle (torque) was a nonlinear function of the magnitude of the disturbance. The torque was proportionally larger for small disturbances than it was for large disturbances. This general nonlinear shape was observed regardless of the initial torque or position, but the magnitude of the torque increase was larger with larger initial torques. That is, the stiffness increased with initial torque. The contribution of the passive stiffness to the total stiffness was significant, but was usually less than 25 percent. The dependence of stiffness on initial angle has not yet been studied systematically.

The responses also showed hysteresis. A torque increase (producing joint extension) followed a short time later by an equal but opposite torque decrease did not move the joint back to its original position. Instead, the joint stayed at a slightly more extended position. The magnitude of the hysteresis increased with the initial torque.

In summary, the stretch reflex properties have been shown to depend in systematic ways on the initial torque and the amplitude and direction of the disturbance. This indicates that the mechanical properties of the muscles with reflexes intact are not well regulated, and that quantitative comparisons of stretch reflexes in normal subjects with those in subjects with movement disorders can only be carried out with careful matching of the experimental conditions ■

NIHR REC

QUANTITATIVE INTERPRETATION OF EMG DURING GAIT

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This project is directed at demonstrating the utility of the derived relationships between physical muscle variables and the onset of the MES to clinical treatment. While many isolated parameters of gait, including joint moments and mechanical energy, have been studied and have been shown to elucidate the mechanics of walking, muscle length and rate of change of length have been largely ignored.

A general three-dimensional mechanical model of the lower-limb musculature was developed to approximate muscle length changes in both normal and pathological gait.

Based on muscle length, lengthening velocity, and MES data, the following results were obtained from a limited study of normal gait:

1. The tibialis anterior and hamstrings begin their electrical activity at their peak lengthening velocity;
2. Two-joint muscles show less change in length per unit length during gait than one-joint muscles, due to the interaction of joint rotations;
3. The knee joint is less influential than the ankle or hip joint to the length changes in two-joint muscles;
4. Before the period of weight acceptance, vasti muscles are fully active and ready to work in a springlike manner.
5. The muscle lengths show differences as a function of walking speed, especially when muscles are actively shortening.

Based on muscle activity and external joint moments, we observed that two-joint muscles showed electrical activity in phase with the external joint moment at the distal joint. Co-contraction appeared to be present whenever needed for stability of posture. Co-contraction across the hip and knee was found whenever the joint moments were small, i.e., whenever there was a possiblity of a moment change from flexion to extension or vice versa, even if the moment does not actually change direction. An exception occurs when the vasti muscles are preparing for weight acceptance by activating before heel strike.

Thus far, we have investigated the relationships between muscle electrical activity and mechanical parameters for three spastic patients. In these subjects with equinus gait, reflex activity in the calf muscles right after heel strike could be determined (i.e., as the muscle was rapidly lengthened in a ramp [linear] mode, the ankle joint moment increased with about a 50 msec latency). But in the period of weight release, the calf muscles do have an active role in producing power at the ankle joint as in the normal case. Additionally, the spring-like behavior at the knee during the period of weight acceptance was not observed in these patients as it was in normal subjects. The knee joint was steadily extending from the beginning of the period by the extension torque at the hip joint.

Finally, the pattern of electrical activity in the pathological cases differed from that seen in the

normal cases. In the normal cases, the MES showed a gradual rise in amplitude to a maximum followed by a relatively sharp drop in amplitude, while the pattern was just the opposite in the pathological cases ■

NSF

MODELING, CONTROL, AND SIMULATION OF HUMAN MOVEMENT

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This research program continues support of work in the areas of modeling, control, and computer simulation of human movement. The research encompasses four areas, as follows:

1. Modeling of the dynamics of human movement embodying the skeleton, ligaments, and muscles;
2. Control of movement through muscle activity, gravity, support, and joint structure.
3. Digital computer simulations to verify and confirm validity and effectiveness of the models and the control algorithms, and comparison of these simulations with available physiological measurements.
4. Development of a modular computer network for the above studies.

This is a 3-year continuing grant ■

NSF

ENGINEERING MODELING OF NEUROLOGICAL CONTROL MECHANISMS

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The research objectives are the systematic identification of the dynamics of the human motor system; the definition and determination of the parameters of its various components by means of mathematical modeling. Movement around the ankle, the elbow, and the wrist joints will be studied for the investigation in normal human subjects. The stretch reflex will be used as a test probe to study underlying neural mechanisms of posture and to measure system changes during control of voluntary movements.

The expected results are a better understanding of (i) input-output characteristics of the components of the motor systems and their equivalent mathematical models, and (ii) the motor functions at the spinal cord level in normal human subjects ■

NSF

EMG SIGNATURE DISCRIMINATION FOR CONTROLLING ELECTRICAL STIMULATION OF PARALYZED LIMBS FOR PARTIAL FUNCTIONAL RESTORATION

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We propose to continue research on combining EMG temporal-signature-discrimination-based control of functional electrical stimulation of paraplegics and stroke-related hemiplegics. These concepts, using above-lesion EMG signal signatures, have successfully been applied to a T-6 complete paraplegic who thus accomplished standing up, sitting down, and several primitive walking steps between bars (for balancing, not weight-carrying), at complete EMG control (and no hand-switch control). We propose to continue this research, concentrating on filtering of the effects of spasticity on the EMG signature control, and the use of EMG feedback from the stimulated limbs in the control system for the purpose of separating the stimuli signals from the feedback EMG.

System size reduction and the speeding up control will also be undertaken ■

NIH MUSCULOSKELETAL

CONTROL OF HUMAN LOCOMOTION

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A neglected field has been the contribution of operant conditioning to human locomotion. The proposed work will continue to study operant (discriminative stimulus) control of muscle electrical activity, EMG, and movements as people walk on a motorized treadmill.

One major aim of the work is to understand cooperation or competition between muscles of different actions or at different joints when coordination is controlled by public events that are remote from the moving muscle. Separate or co-control that is produced over one or more muscles may reveal possibly obligatory neural or biomechanical machinery. A computer will deliver lights, judge subsequent EMG responses, and deliver a high or low tone after a success or failure, respectively.

A second major aim is to search for presumptive movement-produced stimuli — private events, such as mechanical deformations of tissue that excite

proprioceptors or tactile receptors.

During the coming year, work to date for both aims will be summarized and extended. This work has shown an extensive role for operant conditioning in human motor control. Wholesale shifts in rhythmic locomotor patterns will continue to be examined for their implications as to eye-limb coordination. In addition, investigations so far have amply documented the existence of movement-produced stimulation. In the next year, some experiments will attempt to specifically condition such "private" control.

Results as a whole will help to establish the reflexive or acquired origins of movement to aid understanding of (i) bodily mechanisms of rhythm generation, and (ii) learning of movements and/or movement sense by normal or gait-disordered individuals ■

NIH MUSCULOSKELETAL

LOCOMOTION — BLOOD FLOW AND METABOLISM

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The long-term goals reflected in this project are:

1. To determine the manner in which muscles and populations of fibers within muscles are recruited during locomotion; and

2. To investigate the relationship between muscular activity and muscular metabolism.

In previous work, the spatial recruitment patterns that occur within and among mammalian muscles during exercise have been described. Also, it recently has been found that the magnitude and distribution patterns of blood flow within and among muscles of rats vary with the fiber-type composition of the muscles and with locomotory speed, and that muscle blood flow increases at a constant speed with time during exercise to fatigue.

It has been concluded from this work that muscle blood flow patterns are closely related to muscle fiber recruitment patterns. Two immediate questions emanate from previous work:

1. Are the absolute magnitudes and the patterns of blood flow observed with and among the rat muscles representative of other mammals, or are they unique to laboratory rodents?

2. Are progressive changes in muscle fiber recruitment responsible for the gradual elevations in muscle blood flow that occur over time during exercise, or are other mechanisms involved?

To answer the first of these questions, blood flows within and among the muscles of pigs and dogs will be determined during exercise. To answer the second, three hypotheses will be tested that may explain the progressive increases in muscle blood flow that occur with time during exercise: that (i) the elevations result from progressive recruitment of additional motor units in the muscles as fibers fatigue; (ii) that the elevations result from a progressive rise in body temperature; or (iii) that the elevations result from progressive accumulation of vasodilator substance in the muscles. Answers to these questions would significantly further understanding of the patterns of muscle fiber activity that occur during exercise and accompanying metabolic support of the muscular activity ■

VA RR&D CENTER PALO ALTO

THE SPINAL LOCOMOTION PATTERN GENERATOR IN HUMANS

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Need — Spinal cord injured patients and others with severe gait disorders have the need to walk in order to improve their mobility and gain independence.

Current techniques to restore locomotor function in these patients have revolved about either the use of external mechanical aids (walkers, crutches, canes, etc.) or, more recently, the use of functional electrical stimulation to activate select groups of lower-limb muscles. For a combination of technical and cosmetic reasons, these approaches have, in general, not led to restoration of walking for the disabled community. All of these solutions chose to ignore the possible presence of any intact spinal cord control of lower limb muscles.

Approach — Extensive experimental work over the past few decades has shown that many mammals (e.g., dogs, cats, rabbits, rats) can perform stepping locomotor activity after a complete spinal cord transection. These spinal stepping experiments have led to a much better understanding of spinal cord function in the control of locomotion. However, one investigator's attempt to extend this experimental work to primates has failed to elicit rhythmic limb activity. There have been few reported attempts in the literature to systematically observe the presence (or absence) of stepping in spinal cord injured patients. It is therefore unknown whether human sub-

jects with spinal cord transection can perform rhythmic stepping movements with their legs suspended above a moving treadmill.

It is the thesis of this study that humans possess some form of spinal "pattern generator" for locomotion.

Volunteer patients will be suspended in a modified parachute harness over a moving treadmill belt. The sole stimulus to the patient will be a plantar contact of his foot with the belt. Any leg movement will be recorded with a video system, while electromyographic activity will also be measured from lower-limb muscles.

Status — The outcome of this proposed work will have a significant impact on the course of future spinal stepping experiments in both humans and animals. The absence of locomotor activity in humans would force neurophysiologists to re-examine existing models for spinal cord injury, and perhaps work more extensively with preparations that better resemble those found in spinal cord injured humans. On the other hand, the presence of spinal stepping in our subjects would strengthen the relevance of existing animal work in the area, and create the groundwork for more quantitative studies with human subjects. Evidence leading to the existence of spinal "locomotor pattern generators" would be an exciting development, suggesting the possibility of simple controllers for the generation of locomotion in humans with spinal cord injuries ■

NIH MUSCULOSKELETAL

MEDIAL GASTROCNEMIUS MUSCLE FUNCTION IN LOCOMOTION

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The specific hypothesis that the central nervous system control of locomotion is focused on distinct parts of individual muscles, rather than whole muscles or synergistic groups, will be tested by recording the activity of single motor units in distinct parts of the triceps surae muscle group of cats during a broad range of stepping behaviors. Each motor unit recorded will be carefully characterized using physiological criteria, and its location in the muscle examined by glycogen depletion and histochemical analysis. The pattern of recruitment of motor units in each part of each of the muscles will be correlated with the physiological properties of those units. These patterns will then be compared between different parts of the muscle to determine if motor units are recruited with any level of independence in different parts of the same muscle.

The results of this study are expected to have significance in establishing guidelines for studies of the mechanisms and the specificity of motor control during behavior. They are also anticipated to be of use to clinicians, especially in neurology and rehabilitation medicine, in the diagnosis, treatment, and evaluation of patients with disorders of movement, especially those involving the locomotor apparatus ■

NIH MUSCULOSKELETAL

ORIGIN OF LIMB POSITION AND MOVEMENT SIGNALS IN HUMANS

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This project will study how the awareness of static limb position and the sense of limb movements in humans are derived from sensory inputs from joint, skin, and muscle. The tests involve matching one limb or digit to its opposite, detecting movements or misalignments from the matched position, and estimating the magnitude of a misalignment or the speed of a movement. Using healthy adult volunteer subjects, tests will first be done to develop procedures that can distinguish movement sense and position sense, and then to establish baseline performance levels. Evidence indicates that these two senses are different. The effect of eliminating various inputs using local anesthetic block will then be tested. Some tests will use patients having a complete rupture of the Achilles tendon.

A major goal is to test the hypothesis that muscle spindles provide necessary and sufficient sensory input for limb position sense, and that skin and joint contribute little or nothing. The hand is an exception; cutaneous inputs are in some way involved in kinesthesia in the fingers, but not in other joints, like the knee. How the hand differs in this and other respects will be tested.

Finally, whether gamma control of spindle activity is essential to position accuracy will be tested in subjects (i) with relaxed muscles; (ii) with partial (gamma) block of motor nerves; and (iii) using recordings from spindle afferents in humans to see if there is a change (reflecting gamma activity) during position discriminations.

Once the source of the position and movement detectors and more about coding and fusimotor control are known, meaningful experiments on animals can be done for detailed neurophysiological research ■

VAMCRICHMOND

SINGLE UNIT STUDY OF MUSCLE AFFERENTS IN HUMAN MOVEMENT

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An electrophysiology laboratory has been established at the VA Medical Center, Research Service, Richmond, Virginia, to monitor and record single unit afferent nerve potentials from muscle receptors in the awake, unanesthetized human. The major receptor presently recorded is the muscle spindle, although the golgi tendon organ, and cutaneous receptors such as touch, pressure, and joint receptors, are readily recorded. Potentials are recorded from the median nerve at the elbow and mid-upper arm, and the posterior tibial nerve in the popliteal space. Electromyograms and joint range are simultaneously recorded with the receptor action potentials.

Single unit action potential activity is recorded using manually inserted insulated tungsten wire electrodes, electrolytically tipped and impedance-measured at 100–150 kilohms at 1,000 hertz. Electrical stimulation through the recording electrode allows for muscle receptor nerve fascicle isolation, which results in a rapid muscle spindle nerve fiber location.

A device to record wrist and finger range of movement is being custom designed and fabricated, in cooperation with Bioengineering and the Orthotic Laboratory. The device should be available for experimental testing in the near future.

A Texas Instruments 990-5 computer is being incorporated into the system to initiate programs for quantitation of results.

Preliminary recordings in normal subjects are directed at determining criteria for receptor identification and monitoring muscle afferent activity during rest, passive stretch, muscle twitch, reflex, and voluntary movement. Initial records suggest that some receptors fire spontaneously at rest (as determined by the lack of electromyogram and torque changes), and that receptors can be facilitated by remote muscle contractions without initiating overt contractions of the receptor-bearing muscle.

It is projected to study muscle afferent activity in patients with hyperactive syndromes and phasic movements (Parkinsonian and cerebral vascular accident patients). The overall objective of the project is to study the interactions of the alpha motor-fusimotor systems in human normal and pathological movement ■

NIHR REC

DEVELOPMENT OF MATERIALS FOR IMPROVED IMPLANT / TISSUE COMPATIBILITY: PERCUTANEOUS PASSAGE

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Objective: The overall project objective is to develop a permanent percutaneous implant. The purpose of this section of the project was to determine if epidermal ingrowth is necessary in the development of a successful percutaneous implant.
Summary: 24 porous vitreous carbon implants and 18 smooth pyrolytic carbon implants were implanted in six minature pigs as percutaneous devices. The implants were harvested through a 10-week time span. Histologically, the surrounding tissue reaction exhibited an intense inflammatory response at the 8-week and 10-week time periods. All of the vitreous carbon implants failed at the 10-week harvest due to fracture of the implant. Both types of implants were concluded to be unsuccessful percutaneous devices in the present model ■

LIBERTY MUTUAL, NIHR, SWEDEN

NEW ELECTRODES FOR DETECTING MYOELECTRIC SIGNALS

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Many parameters relating to the activity of a muscle during contraction may be studied by analyzing the electrical activity (myoelectric signal) originating from the muscle fibers. This signal can be detected by placing electrode contacts on the surface of the skin directly above the muscle, or by inserting a thin needle containing metallic contacts directly into the muscle. Both surface and needle recording electrodes are necessary to completely evaluate parameters of muscle activity.

To maintain consistent results during surface measurements of the myoelectric signal, a standard surface-recording electrode has been developed.

The contacts of the standard electrode are in the form of two one-centimeter-long parallel bars of silver, spaced 1 centimeter apart. The bars are mounted directly on a small epoxy package containing a high-quality preamplifier. Using this configuration, the electrode exhibits the mechanical and electrical stability necessary for low-noise myoelectric recordings. It is hoped that this standard electrode design will be adopted by other researchers.

To analyze activity of individual muscle fibers, an electrode much more selective than the surface electrode is necessary. A needle electrode inserted into the muscle fulfills this requirement. During the past year, an improved needle electrode capable of recording multiple channels of information was designed. A rectangular array of four 75-micrometer diameter electrode contacts was fabricated in the side of a thin surgical needle near its tip. At the other end of the needle, a lightweight plug allows electrical connections to external equipment. Because of its capability to selectively record from individual and/or small groups of muscle fibers, this electrode is particularly useful for detecting muscle signals that may be decomposed, allowing the identification of electrical pulses that are associated with individual muscle fibers.

Both the new surface and needle electrode designs greatly simplify the task of obtaining reliable and accurate signals used to study muscle activity ■

ROBOTICS

VA—JHU/APL

WHEELCHAIR CONTROL AND ROBOTIC ARM/WORKTABLE SYSTEM FOR HIGH-SPINAL-CORD-INJURED PERSONS

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Current Robotic System Described — The APL robotic system utilizes a structured worktable concept, i.e., components are located on the worktable in a manner that allows the robot to use prestored motion trajectories to carry out desired functions. This concept makes manageable, for example, the difficult task of putting a single sheet of paper into a typewriter. To control the robot, the user calls up the desired program by applying an appropriate head motion to a chin controller. The robotic system is designed for the highly disabled person who is unable to use his upper or lower limbs but who has nearly full motion of the head and neck. These residual motions are used to control the system by means of a chin-operated controller mounted on the wheelchair. This controller also enables the quadriplegic to operate the electric wheelchair. This duality of control gives the quadriplegic much-needed mobility as well as the opportunity to perform manipulative activities with the robot arm.

Significant improvements were made to the system to improve the efficacy of the robot arm in performing a variety of activities including user self-feeding, positioning, loading and operating a typewriter, handling a telephone and reading materials, and using a personal computer. Most significant among these new developments is simplified programming of robotic arm motions — this can now be carried out by an occupational therapist or the quadriplegic user himself or herself with substantially less training and effort than previously.

The addition of a chin-operated system for Morse Code input now greatly facilitates use of a personal computer by the quadriplegic user.

The telephone handling system on the worktable has been improved to expedite placing and receiving calls. The modules of the telephone are taken from a standard commercial unit and repackaged to minimize the effort required to use the telephone. The mouthstick is utilized to turn the phone on and to touch-dial the desired phone number through an integrated pulse repertory dialer. The robot arm lifts the receiver from an out-of-the-way position on the work table and delivers it to the user's ear. The arm is then free to perform other functions. The microphone is located in the mouthstick holder on the worktable and can be addressed directly by the user. For maximum privacy, the user has the option of speaking very softly into the mouthpiece end of the mouthstick. The sound is transmitted through the lumen of the mouthstick to a hole in the mouthstick holder which communicates directly with the microphone. This system will be evaluated during the second phase of testing at the Richmond VA Medical Center.

Improved Multimode Self-Feeding — One of the most important tasks that the robot arm worktable system enables the totally quadriplegic user to accomplish is self-feeding. A new development has significantly improved this feeding capability. A spoon has been modified with a wire bail type of clamp. This device allows the user to eat bulky food items such as sandwiches, hot dogs, toast, french fries, or large pieces of lettuce as well as food prepared in bite-sized or smaller morsels. In response to

the user's command signals, the robot slides the spoon beneath the desired item of food. If the user perceives that the food item extends so far beyond the edge of the spoon as to be unstable, the user signals the robot to close the bail down onto the food item. The food item is grasped in a manner similar to fingers grasping a cookie against the thumb. After eating the edges of the food item, the user signals the robot to lift the bail so that he can eat the central remnant directly from the spoon and without contacting the bail with his mouth.

Food may be eaten from two standard bowls or a conventional dinner plate. In the prestored program for bowl eating, the spoon is preprogrammed to go into the bowl, pick up a bite-sized portion, scrape the bottom of the spoon to remove drippings, and proceed to the user's mouth. When eating, the user may switch to any of several eating modes, e.g., from bowl to plate or from plate to bowl. The self-feeding mode was tested at APL and at VA Medical Center in Richmond, Virginia, and found to show significant promise as a practical eating arrangement.

CLINICAL EVALUATION
VA Medical Center, Richmond, Virginia

The system was evaluated by three C3 quadriplegic volunteers, none of whom had any upper limb function. The first worked with the system for 6 weeks and ate 25 meals with it. At the conclusion of his evaluation period, he had formed a very favorable impression of the value of the system. He found the eating capability of this system to be significant since it freed him from having an aide feed him and permitted him control over the order and speed with which he ate his meal.

The second used the system for 1 week and ate 1 meal with it. He rejected the system and withdrew from the project with the explanations that his wife performed all services for him provided by the robot arm, that she did it much better.

The third worked with the system for 3 weeks and ate 13 meals with it. He initially rated the eating function as only "satisfactory." He was especially enthusiastic about using the computer; he elected to spend 19 hours in use of the computer subsystem■

VA RR&D CENTER PALO ALTO

DEVELOPMENT AND EVALUATION OF A ROBOTIC AID FOR THE SEVERELY DISABLED

VA Rehabilitation Research and Development Center
Palo Alto VA Medical Center
Palo Alto, California 94304

■ Participants in the Robotic Aid project were the following:
From the Rehabilitation R&D Center, PAVAMC, and the Design Division, Mechanical Engineering Dept., Stanford University: **Larry J. Leifer, Ph. D.; Urs Elsasser, Ph. D.; Stefan Michalowski, Ph. D.; H. F. Machiel Van der Loos, Ing. Dip.; Charles E. Buckley, M.S.; Charles Wampler, M.S.; John Jameson, M.S.; Walter Conti, M.S.; John Walecka, M.S.;** and **Allen R. Curran, M.S.**
From the Spinal Cord Injury Service, PAVAMC: **Inder Perkash, M.D.**
From the Design Division, Mechanical Engineering Dept., Stanford University: **Bernard Roth, Ph. D.**
From the Rehabilitation R&D Center, PAVAMC: **Karen G. Engelhardt, B.A.**

Need — Severe physical disability, such as that caused by high-level spinal cord injury, leads to a drastic disruption of manipulative capabilities. It is asserted that robotic technology, applied to the needs of the disabled, can help in bridging the gap between individuals whose perceptual and intellectual powers remain intact and the environment they no longer control.

Approach — In setting out to apply robotic technology to the field of rehabilitation, the current state of commercial industrial robotics was used as a starting point, adding those enhancements required to produce an assistive device that can be of use to a severely disabled individual. Specific use was made of the following technological and theoretical advances.

1. The availability of a suitable manipulator;
2. Theoretical understanding of robot motion;
3. Progress in speech recognition and synthesis; and
4. Advances in microprocessor technology.

There exist two distinct versions of the Robotic Aid: a Clinical System and a Laboratory System. The former is a complete manipulation aid whose design is stabilized to a degree that allows intensive evaluation trials at the VA Medical Center in Palo Alto. The laboratory system, located at the Department of Mechanical Engineering at Stanford University, serves as a research tool for developing new hardware and algorithms. Major components of the laboratory system will be integrated into the Clinical System as they reach maturity.

Status — The Clinical Robotic Aid consists of an anthropomorphic electromechanical arm with six degrees of freedom which allows the user to position and orient the hand arbitrarily within a spherical

working envelope of approximately 3 feet in diameter; an Arm Controller comprising six motor controllers and a DEC LSI-11/2 based computer which solves kinematic equations of the arm; and a System Controller in the form of a Zilog MCZ 1/25 computer which serves all input/output devices.

Input devices are: discrete voice recognition unit, two degrees-of-freedom head control unit, six degrees-of-freedom joystick, teachbox, and keyboard.

Output devices are: voice synthesis unit, display console, and flat panel display. There is also a two-fingered hand which is equipped with touch sensors in the form of microswitches located on four sides of each prismatic finger.

The Robotic Aid has been integrated into a custom-designed multipurpose environment that includes a work surface, a microwave oven, a refrigerator, and a number of small appliances.

The disabled user communicates with the Robotic Aid primarily through the speech recognition/synthesis subsystem. A vocabulary for efficient motion control has been designed, and an innovative software environment, UNIZCSYS (for UNIfied Arm Control SYStem), has been created. The manipulator control language allows the user to define the direction of movements and the orientation of the hand in one of three coordinate systems. It facilitates changes of speed through explicit and implicit commands and lets the user choose between continuous and discrete motions. The manipulation vocabulary has undergone several modifications and today consists of 58 commands.

In addition to the real-time control scheme used to "pilot" the manipulator through its workspace, the Robotic Aid can be programmed to go through any desired sequence of motions.

The Robotic Aid is used at the VA RR&D Center in Palo Alto for the purpose of user training and device evaluation. To date, more than 90 people have been trained in the use of the Robotic Aid. One-third of the users are disabled individuals, mostly high-level quadriplegics.

Considerable effort was spent on developing training procedures, including the preparation of a comprehensive manual. A methodology to assess the efficacy of different training techniques was outlined, based on the theory of Locus of Control: this work was carried out in collaboration with the Psychology Department at Stanford University.

The continuing evaluation effort has yielded information leading to significant improvements in system performance. Voice recognition errors in the form of substitutions were singled out as the paramount source of user frustration. Consequently, the control vocabulary was modified to reduce substitution errors, and recognition thresholds were adjusted to favor non-recognition over substitution errors.

An on-line update feature was implemented to eliminate problems with persistently misrecognized words.

Visual cues were included on the manipulator to help the user recognize the system's main axes of motion.

Voice output was improved by choosing better phoneme representations of the synthesized messages.

A miniature hand-mounted TV camera was tested as a means of facilitating manipulation. Users expressed the desire to employ such a system as a viewing device to gain visual access to places that are out of sight for the wheelchair-bound person.

Personal impressions were studied, using formal interviews and questionnaires. The advantages of a Robotic Aid were corroborated by the many users who could imagine such a device in their home settings. Tasks mentioned most often were: obtaining a drink of water, cooking and serving a meal, eating, handling clothes and other personal belongings, and vocational applications.

Pending — Range-Sensing Hand: A hand with improved sensory capability was built. Electro-optical reflective sensors provide range information which can be used to facilitate grasping, the most time-consuming part in manually controlled "pick-and-place" operations. It also allows the user to keep the hand aligned with a surface.

Mobility — The Omnibase: A mobile platform was designed. This mobile base is unique in that it uses the principle of omnidirectionality; i.e., its three degrees of freedom in the plane of motion are uncoupled. The key to this are three wheels, each consisting of a ring of freewheeling rollers arranged along the sides of a triangle. By driving the three wheels in a coordinated fashion, the vehicle can move along any path in any desired orientation. The Omnibase carries with it the manipulator plus all the necessary controller hardware. Battery power is sufficient for a minimum of 1 hour of operation.

Evaluation continues, and is now focused on acquiring data for successful user profiles, and on exploring new applications for vocational and recreational uses of the Robotic Aid ■

MOBILITY AIDS WHEELCHAIRS

VAMC ATLANTA

ANTI-ROLLBACK WHEELCHAIR WHEEL

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Purpose — This wheel is engineered to be an easily retrofitted item for standard manual wheelchairs, to give them the capability of anti-rollback when ascending hills and ramps.

Progress — The first demonstration unit has been completed and has performed in a satisfactory manner. Modifications were made to increase the structural strength of key elements. All calculations for loading and stresses have been completed and preparation of the engineering drawings for a final production prototype is underway.

Future plans — Efforts to construct several units for use in evaluation at the Atlanta Veterans Administration Medical Center will continue as funding permits. The team is continuing to seek commercial interest for the production of the unit ■

NIHR REC

ENERGY COST OF WALKING AND WHEELCHAIR PROPULSION RELATED TO PHYSICAL IMPAIRMENT

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The energy requirements of ambulation and/or wheelchair mobility were studied in spinal cord injury, myelodysplasia, and lower limb fracture patients. Alterations in the relative demand of ambulation caused by varying lower-limb-cast walking surface (cast boots vs. walking heel vs. rocker heel), and by various degrees of restricted knee motion, were documented in normal subjects. All testing was conducted in the Pathokinesiology Laboratory of Rancho Los Amigos Hospital.

Instrumentation and basic test procedure for energy-cost measurement, footswitch gait analysis, and joint electrogoniometry were common to all five studies within this project. Variations in testing protocol unique to each study are described within the appropriate sub-sections of this report.

Oxygen uptake analysis was derived from the modified Douglas Bag collection technique. A thermister was used to detect respiration rate. Heart rate was measured via surface electrodes. Blood pressure was monitored using a standard pressure plethysmograph and stethoscope. Cadence was measured by means of a contact-closing heel switch located in the sole of the subject's shoe on the uncasted side. Indoor testing was performed on a level 15-meter-long walkway.

A contact closing insole footswitch system was used to provide velocity, cadence, average stride length, single and double limb support times, and swing-stance ratio. All data were recorded on analog tape and displayed on an oscilloscope.

In two studies, an electrogoniometer was used to measure dynamic knee motion.

1. Ambulation in Below-Knee Plaster Casts

Results: Subjects using the DePuy walking heel and the castboot showed no significant differences in rate of O_2 consumption ($p<.10$). Both the castboot (.182 ml/kg-m) and the DePuy heel (.187 ml/kg-m) however, were significantly less efficient ($p<.001$) than free walking (.154 ml/kg-m). The average heart rates during ambulation were not significantly different ($p<.02$). Average velocity with the DePuy heel (63.6 m/min was significantly less ($p<.01$) than free walking (73.1 m/min). For this group no significant differences were found in any of the mechanical gait variables.

2. Lower Limb Fracture Patients

Results: Physiological steady-state could not be attained by the majority of patients indicating the rigorous demand crutch-walking places on orthopaedic patients. Respiratory rate evidenced a statistically significant difference between males and females ($p<0.05$), but heart rate did not. Females had a heart rate of 158 beats/min and a respiratory rate of 32.5 breaths/min; while males had a heart rate of 148 beats/min and a respiratory rate of 24.7 breaths/min.

Velocity also showed a statistically significant difference ($p<0.05$) between males and females wearing a SLC. Females walked at a rate of 46.8 m/min, taking 84.5 steps/min, with an average stride length of 1.16 m. Males walked at a rate of 58.0 m/min, took 95.3 steps/min, with an average stride of 1.23 m.

There was no difference between men and women in rate of oxygen uptake or net oxygen cost per meter. Rate of oxygen uptake and net oxygen cost per meter were 12.4 ml O_2/kg-min and 0.26 ml O_2/kg-m respectively for females; and 15.5 ml O_2/kg-min and 0.27 ml O_2/kg-m for males.

The type of cast led to a statistically significant difference in both heart rates (Fig. 1) and respiratory rates. Patients ambulating with SLC had a heart rate of 153.7 beats/min and a respiratory rate of 29.1 breaths/min, which was greater than those patients with LLC who had a heart rate of 130.3 beats/min and a respiratory rate of 18.4.

Stride characteristics evidenced no statistically significant differences between the two cast groups but both were slower than normal. Velocity (Fig. 2)

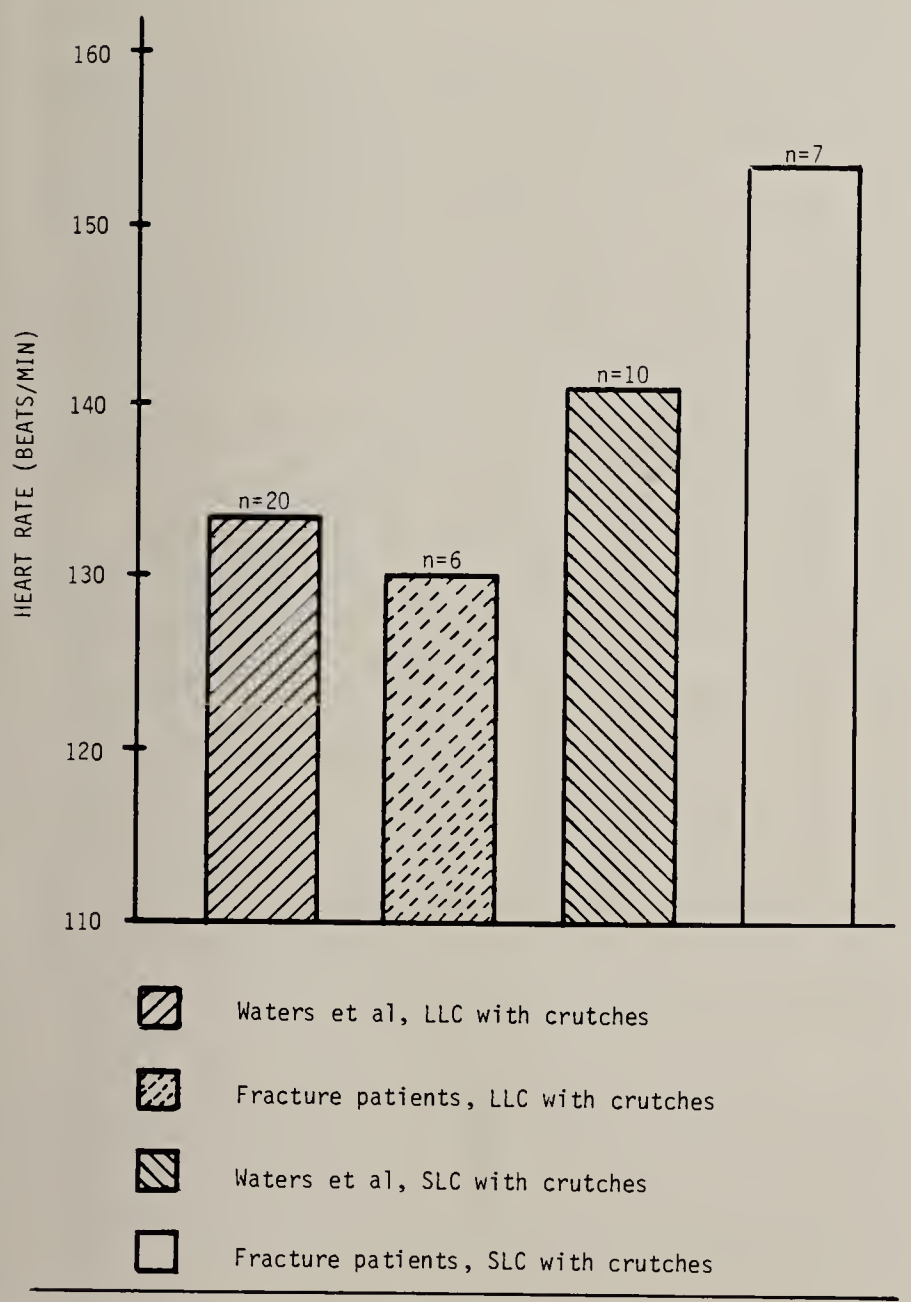

FIGURE 1.
Comparison of values for heartrate of normal adult males and normal fracture patients.

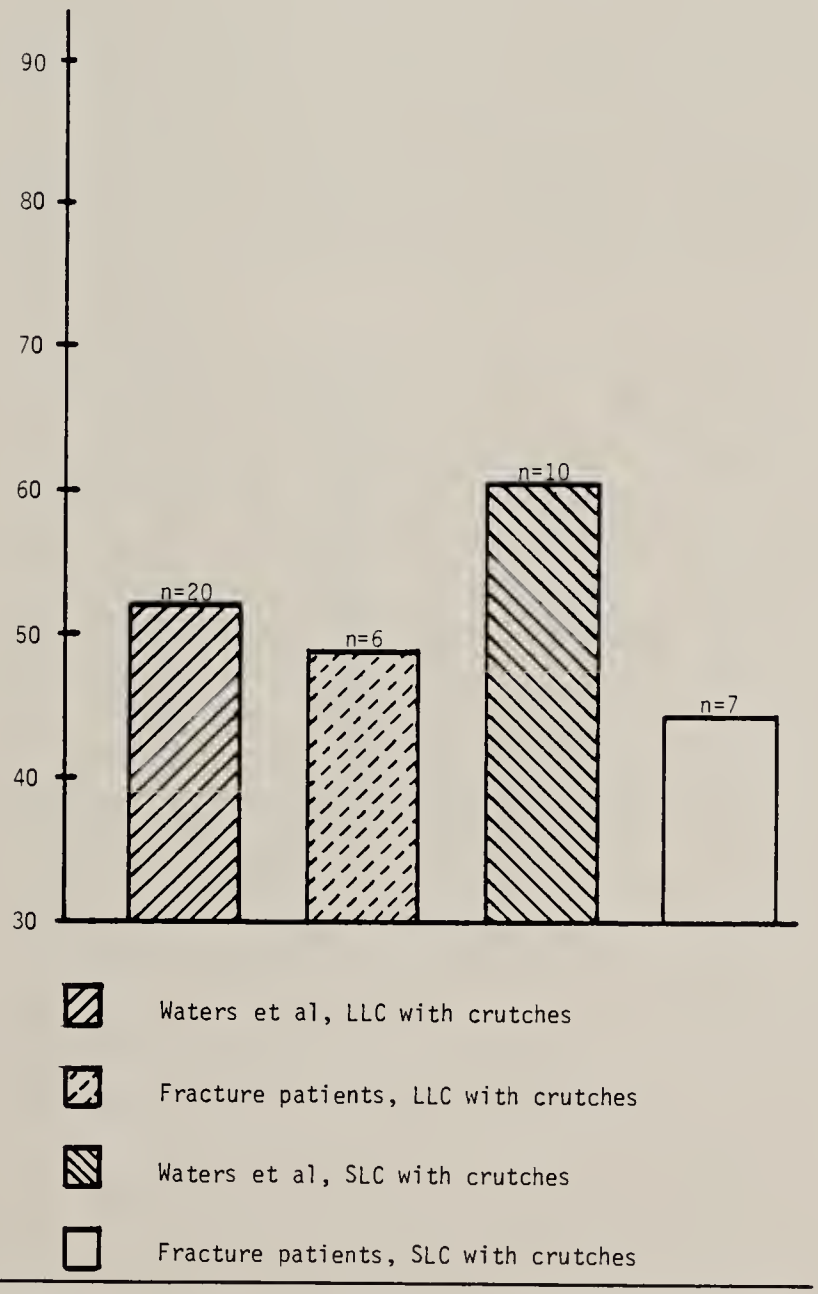

FIGURE 2.
Comparison of values for velocity of normal adult males and normal fracture patients.

was 43.9 m/min, with cadence of 89.1 steps/min and average stride length of 1.16 for the non-weightbearing gait of the SLC patient. The LLC ambulator walked at a velocity of 48.7 m/min, having a cadence of 80.0 steps/min and taking an average stride length of 1.20 m.

There was a statistically significant difference in net oxygen cost per meter between patients ambulating with a SLC versus the less efficient LLC ($p<0.05$), but not in rate of oxygen uptake. Rate of oxygen uptake for SLC ambulators was 13.7 ml O_2/kg-min with a net oxygen cost of 0.26 ml O_2/kg-m; while patients ambulating with LLC had a rate of oxygen uptake of 16.2 ml O_2/kg-min with a net oxygen cost of 0.35 ml O_2/kg-m.

3. Ambulation with A Flexed Knee

Results — Oxygen consumption was increased at all three values of knee restriction (Fig. 3).

Velocity was significantly reduced in all restricted walking trials ($p<.01$).

Stride length demonstrated the same pattern as velocity. At 20 degrees of restriction, mean stride length was 1.28 meters, a significant decrease from 1.37 meters when knee motion was unrestricted ($p<.01$).

Significant changes in peak angle ranges between unrestricted and restricted walking were evident. Dorsiflexion increased significantly at 20 degrees of knee flexion to 10 degrees, from 8 degrees of dorsiflexion seen with no knee restriction ($p<.01$). Mean plantarflexion with unrestricted walking was 25 degrees.

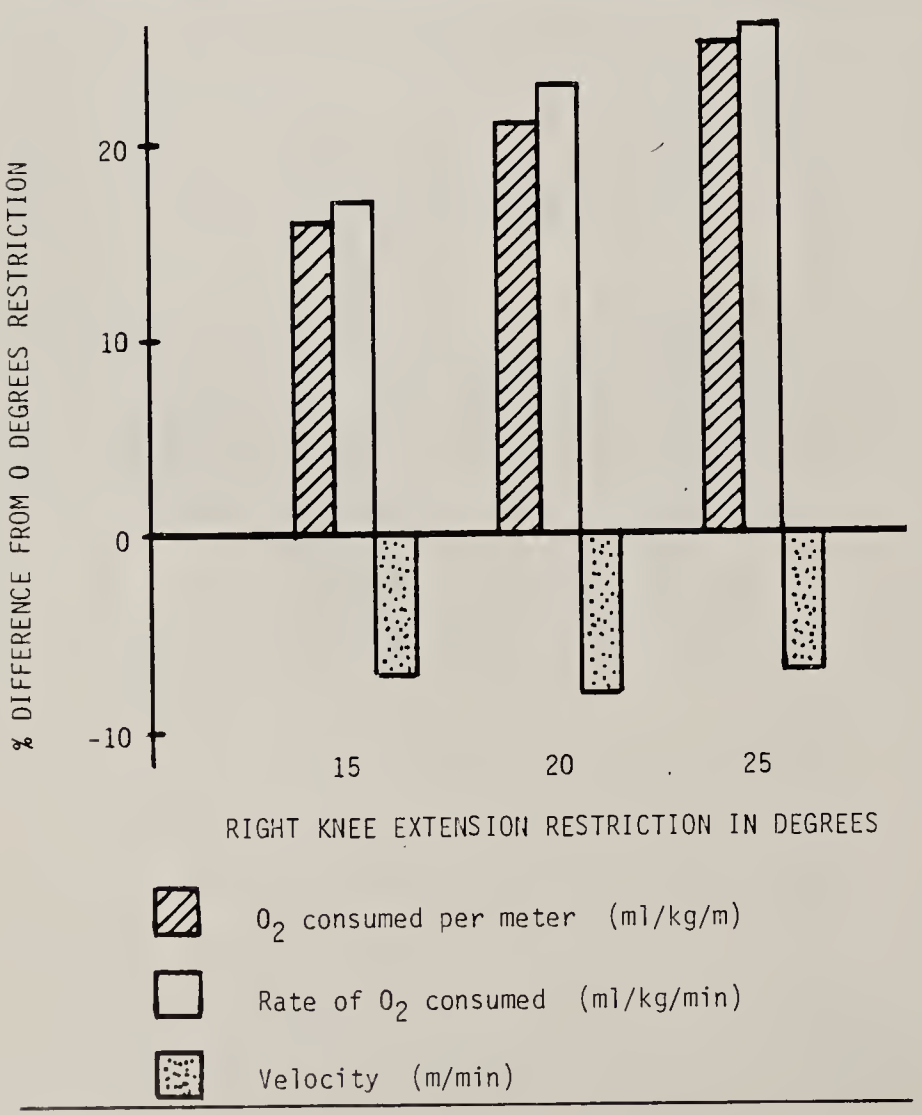

FIGURE 3.
Changes in means of selected O_2 and gait variables with right knee extension restriction.

4. Walking and Wheelchair Propulsion in Myelodysplasia

Results — Six of eight patients requiring bilateral KAFOs preferred walking with a swing-through crutch-assisted gait. Three of six patients using only one KAFO (with or without an AFO on the opposite limb) preferred walking with a reciprocal gait and crutches. None of 14 patients using only AFOs chose a reciprocal gait pattern.

Wheelchair Propulsion: Wheelchair ambulation proved to be the least costly and most efficient means of transportation.

5. Walking and Wheelchair Propulsion in Spinal Cord Injury

Results

Wheeling Versus Walking: A statistically significant difference was found in all measured parameters when wheelchair propulsion was compared to walking. The mean heart rate was lower (121 bpm versus 140), velocity higher (73 m/min versus 28), rate of oxygen uptake lower (11.4 ml/kg-min versus 14.3) and efficiency better (94 percent versus 31 percent) during wheelchair propulsion.

Level of Injury: Partitioning patients by their level of neurological spinal cord injury did not prove a sensitive index of energy expenditure.

Orthotic Management: The amount of partial motor recovery below the highest normal neurologic level proved the most sensitive indicator of energy cost. The group with bilateral KAFOs employed a swing-through gait. The rate of oxygen consumption was higher (17.1 ml/kg-min) than either of the other two groups (bilateral AFOs and KAFO/AFO) who used a reciprocal gait (14.3 and 14.1 ml/kg-min). There also existed a significant difference in the energy cost per-meter-travelled between the bilateral KAFO user and those who wore a KAFO and AFO (.59 ml/kg-m versus .36).

No substantial differences were found between the KAFO/AFO subjects and those in bilateral AFOs. Both had a similar velocity (30 m/min versus 26), rate of oxygen consumption (14.1 ml/kg-min versus 14.3), and energy cost (.36 ml/kg-m versus .46) ■

MOBILITY AIDS
WHEELCHAIR ACCESSORIES

VA RR&D CENTER HINES

FOR WHEELCHAIRS: A HEELSTRAP RETRACTOR AND A SHOCK-ABSORBING SEAT SUSPENSION SYSTEM

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Heelstrap Retractor — The heelstrap on many unpowered wheelchairs can lead to situations that are both troublesome and hazardous. In order to get out of the wheelchair, the user most position the footpedals vertically. This can be done only if the heelstraps are forcefully pushed toward the front of the footpedal. If that is not done, the heelstrap prevents vertical positioning of the footpedal and the footpedal then presents an obstacle that could trip the user as he leaves the chair.

The heelstrap retractor solves this problem by forcing the heelstrap to the proper position as the footpedal is raised. This is accomplished with an inexpensive coil spring that is easily attached to the chassis of the wheelchair. A thin metal finger at the end of the coil spring contacts the heelstrap. Raising the footpedal causes the finger to rotate, pushing the heelstrap forward and out of the way. This eliminates potential hazards and makes it easier to vertically position the footpedal.

Reproduction samples of the heelstrap retractor are available for consumer evaluation.

Seat Suspension — Road shocks and vibrations pose a crucial problem to users of unpowered wheelchairs. The severity of the problem can range from an annoyance to aggravation of pressure sores (decubiti). Many suspension systems have been posed to minimize the problem.

The problem with most is that they require extensive modification of the wheelchair. Manufacturers are reluctant to adopt such designs. This Center's design does not require such modifications to the wheelchair. Rather than adding suspension to the chassis, as in previous designs, this design has suspended the seat. Suspension is accomplished with spring-loaded, post-type shock absorbers located between the upper and lower parts of the wheelchair chassis. A shock absorber is located near each corner of the seat ■

NIHR REC

THE SIMPLE WHEELCHAIR INSERT

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The purpose of the project was to develop a low-cost, wheelchair-based postural insert for cerebral palsied children with mild quadriplegic involvement, in the 7 to 10 year age bracket. Nearly all commercially available inserts are not specifically designed for this group of children. The moderately involved child requires relatively less postural support and restraint than is commonly offered, but more freedom in mobility for transferring and for self-propelling a wheelchair. This disparity between the child's needs and the features offered by the commercially available systems is further aggravated by the relatively high price of between $800 to $1200 for commercially available insert systems. This system is designed to be low in cost and simple enough to install and adjust without specialized technical input.

The design of this device was started by considering the needs of the user in seating, mobility, and equipment management. A desired posture was identified, as was the level of support likely to be needed to achieve it as applied over different body segments.

Anthropometric data was gathered, and the compromises were made for fit, support, and adjustability. All the while, in the background, consideration was given to the manufacturing process. It became apparent that the chief trade-off here was the simplicity of manufacture for adjustability of the device.

Initial design has been completed. A prototype is available for brief trials by San Francisco Bay Area disabled children who meet the criteria for age, size, and diagnosis. The investigators are interested in determining how well the simple wheelchair insert meets the functional needs for support and mobility, if it is appropriately sized and proportioned, and how it is received by the primary and secondary users.

Following design refinements, prospective manufacturers will be contacted and asked to tender submissions for commercial production of the seat ■

NIHR REC

AN EVALUATION METHODOLOGY FOR COMPARATIVE TESTING OF MODULAR SEATING SYSTEMS

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A Side-by-Side Trial methodology was developed at the Rehabilitation Engineering Center, Children's Hospital at Stanford, as a process to evaluate functional and technical features of four commercially available modular wheelchair seating systems and to determine: (i) the specific features and components of a modular seating system which improve or decrease user function, (ii) technical modifications which could be made on existing seating systems to better meet functional needs of users, and (iii) necessity for the development of a new modular seating system. Using a side-by-side evaluation methodology, child subjects with the diagnosis of cerebral palsy are fitted in each of the four seating systems and perform specific functional activities. Each seating system is rated on ability to provide postural control, effects on certain functional activities, manageability by a parent, and technical characteristics.

It was found that a modular seating system that effectively positioned a child had a positive effect on performance of most functional activities. Components of the system, however, can restrict some functions. Fixed footrests, and abduction units that were not user operable, decreased performance in transfers. The relationship between a modular seating system and its wheelchair base influenced effectiveness of the system. The relationship of the footrests to the seating system affected overall posture. The relationship of the seating system to location of the wheels influenced mobility. Appearance was important to therapists and parents and was generally the first feature considered when assessing a system. Although manageability of a system by a parent was considered important, the parent tended to place the child's needs first. They indicated a willingness to put up with a cumbersome system if it helped improve posture and function of their child.

The Side-by-Side Trials have been a useful method of gathering comparative information about modular seating systems. The methodology developed for this project could be useful in the comparative evaluation of other seating systems and other assistive devices ■

NIHR REC

EVALUATION OF AN ANTI-THRUST SEAT

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The Anti-Thrust Seat was developed in 1981 by the REC Special Devices Service. The seat was designed to control the unwanted forward motion of the pelvis which is exhibited during extension, particularly in those clients with cerebral palsy. The design has also proved successful in controlling forward pelvic drift in clients with muscular dystrophy, myelomeningocele, spinal cord injury, and others with no active extension but who exhibit a tendency to "slip out" of the wheelchair seat.

The Anti-Thrust Seat is currently undergoing clinical evaluation by the REC research staff to determine its effectiveness in maintaining upright posture, inhibiting involuntary movement caused by abnormal reflex patterns, and thereby decreasing the frequent repositioning required to maintain an optimal seating position.

These preliminary data are encouraging. Fifty percent of the subjects report that repositioning is never necessary, that 87 percent are able to sit in the Anti-Thrust Seat for approximately 5 to 8 hours or more per day with an optimal amount of comfort (four of five on scale of one to five). Fifty-seven percent of the subjects report an improvement in posture particularly in the cerebral palsied segment of the subject population. And 92 percent report the seating system is comfortable.

The evaluation of the Anti-Thrust Seat thus far suggests some design modifications. These include decreasing the thickness of the front edge of the wedge cushion with possible changes in the plastics used for the solid base. In general, the preliminary clinical trial results suggest that the Anti-Thrust Seat design is effective in the treatment of seating problems frequently occurring as a result of cerebral palsy or other muscular diseases which affect gross motor patterns and therefore postural control. Possible directions for future research are: (i) further clinical evaluation of the Anti-Thrust Seat design on a larger subject population, (ii) study of the effect of the Anti-Thrust Seat in reducing muscle tone, and (iii) longitudinal study on the long-term effectiveness of the Anti-Thrust Seat in decreasing the need for surgical intervention to control contractures and other deformities.

Negotiations are currently underway with potential manufacturers to make the Anti-Thrust Seat available commercially ■

MOBILITY AIDS
CONTROLLERS AND LIFTS

VAMC ATLANTA

ALTERNATE VEHICLE FOR THE PHYSICALLY DISABLED: A FEASIBILITY STUDY

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Rehabilitation R&D Program
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To design systems and subsystems for an alternate to present powered wheelchairs. This is a graduate feasibility study.

Progress — The first electronic control system is under construction with the power modulator system driving actual wheelchair motors in bench testing. Programmable portions of the control system have been designed using an 8748 microprocessor. The printed circuit board has been constructed and encoder construction has begun. Initial testing of the power circuits under loading has been successful and the system is functioning reliably with high efficiency.

Future plans — Plans are to continue construction and within 3 months to implement the system on a present wheelchair to determine its ability to meet user requirements dynamically. An effort is being made to locate a manufacturer for the system, since it can be used with present powered chairs as well as with potential future models of differing design ■

HHS, NIGMS Grant

MYOELECTRIC CONTROLLER FOR ORTHOTIC/PROSTHETIC SYSTEMS

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The aim of this project is the development of techniques and implantable instrumentation necessary of high-spinal-cord-injured patients and amputees to obtain multiple command control signals from residual musculature, in order to activate upper-limb orthotic and prosthetic appliances. Emphasis will be given to producing command signals with sufficiently high signal-to-noise ratios for the execution of finely controlled movements ■

VA RR&D CENTER HINES

NEW DESIGNS FOR PERSONAL LIFTS

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For many disabled people, a lift is required for transfers in and out of a wheelchair. The most commonly used lifts are large, heavy, and difficult to maneuver. Despite these liabilities, current designs present a simple solution that works well.

Over the past few months, this Center has worked to develop a design for a personal lift that would retain the desirable features of simplicity and efficiency while avoiding the problems of size and weight.

One design replaces the heavy metal construction of standard lifts with lightweight composite graphite. This effects about a 50 percent weight reduction without sacrificing strength or stability. The basic design of the lift was retained for its simplicity and efficiency. We are now in contact with manufacturers regarding projected market costs of our new design.

The other design completely replaces current lifts. It attempts to combine the function of both a lift and a powered wheelchair. The new "Proteus-Lift Chair" is designed for individuals who cannot transfer independently, such as the spinal cord injured (C5 through C8), cerebral palsy and geriatric patients etc. The new "Proteus-Lift Chair" (i) eliminates the need to store and/or transport two separate (wheelchair and patient lifter) units; (ii) makes it unnecessary to manually push or pull patients while they are suspended from the liftpost — the drive mechanism of the unit accomplishes these tasks; (iii) can lift patients electrically, using the batteries of the unit as a power source if this option is desired; (iv) can "reach around" bathroom fixtures such as a toilet or washbasin and can reach under furniture with not more than 3 inches of clearance; and (v) has detachable low-profile front casters needed to negotiate the 3-inch floor clearances mentioned above. Standard-size casters can be attached easily to the chassis to give the lift chair unit the identical capabilities of conventional power wheelchairs.

The purpose of the new lift/chair design is to provide a better, safe way to transfer the severely disabled from place to place and to eliminate much of the need for physical strength on the part of the assisting individual ■

VA RR&D CENTER PALO ALTO

ULTRASONIC HEAD CONTROL UNIT

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Palo Alto VA Medical Center
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The Ultrasonic Head Control Unit (UHCU) is an electronic device that is designed to allow quadriplegic individuals to express their will and control their environment. Two Polaroid ultrasonic sensors are employed in this design. In the commercial application, camera focusing is accomplished by ranging the distance from the camera to the subject. In this rehabilitation application, two separate sensors are directed at the user's head. The two distance ranges, one from each sensor to the head, and the fixed separation of the sensors, describe a triangle whose vertices are the two sensors and the user's head. The offset from the base line and center line of the two sensors can be calculated from a set of geometric relationships. This information is then used to map the user's head position into a control space.

The main advantage of this type of interface is that no mechanical contact between the sensors and the user's head is required. That effectively separates the user from the device being controlled. Users should not feel "wired up" or confined, as is frequently the case with other interfaces. The remote-sensing nature of the UHCU should result in a socially acceptable and cosmetically pleasing man/machine interface.

Another desirable characteristic of the UHCU is its speed of operation. Typically, 20 samples of head position are acquired per second. Devices that the UHCU controls, can thus be manipulated quickly. The UHCU can be directly substituted in many applications where a joystick is currently utilized. The real-time action and proportional-control nature of the UHCU make it faster to operate, and more precisely controllable, than the discrete-command characteristics of voice recognition units.

Status — Several applications of the UHCU are being considered and one has been implemented. In a mobility application, the UHCU has been attached to an electric wheelchair. The user of the "Smart Wheelchair" tilts his/her head in the direction that he/she wishes to travel. The farther the head is tilted off the vertical, the faster the wheelchair travels in the direction of the tilt. Two versions have been constructed; one utilizing an Everest and Jennings Model 3P, the other employing an Invacare Rolls IV manual chair that has been motorized with the addition of a Solo Products Power-Pac. In this application, the user initiates head control operation by activating a switch with the back of his/her head. The UHCU then performs a calibration sequence by ranging to the user's rest head position. The device then activates the wheelchair motors and the user can then command the motion of the chair. At any time, the user can press the head switch to stop the chair. In both designs, the sensors are mounted behind the user, so that maximum access to the chair for transfers is obtained. These wheelchairs are currently undergoing evaluation.

Pending — Several other applications of the UHCU are being implemented. In the first of these, the unit will be incorporated in the robotic arm system. The arm's voice-command mode will be retained and head-position control will be added. It is hoped that the UHCU, with its real-time input, will augment the discrete and relatively slower input that voice command produces. By combining the two input mechanisms, a more efficient robotic arm control is anticipated.

The next application uses the UHCU as an alternate input for a commercial communication board. This two-dimensional board uses either a single switch or a joystick to access the letters or words at each row-column location. The UHCU will be used in its joystick emulation mode to allow physically disabled speech impaired individuals access to communication.

The final application is similar to the previous one. In this project, however, the display portion of the communication device is a CRT or a custom display. In this manner, the letter or word at each row-column location can be dynamically changed. By employing an anticipatory scheme (the next letter or word is conditioned by the previous selection), the time to construct a given word or sentence could be reduced. This type of product, a head-position-controlled keyboard, has both vocational and communication applications ■

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[1]Dr. Gaines is with the Spinal Cord Injury Service, Palo Alto VA Medical Center (PAVAMC).
[2]Margaret Barker is with the Rehabilitation Engineering Center, Children's Hospital at Stanford.

VA RR&D CENTER PALO ALTO

DEVELOPMENT AND EVALUATION OF WHEELCHAIR FEEDBACK CONTROLLERS

VA Rehabilitation Research and Development Center
Palo Alto VA Medical Center, Palo Alto, California 94304

■ Participants in the Wheelchair Feedback Controller project were the following:

From the Rehabilitation R&D Center, PAVAMC: **Robert E. Smith, MSME; William H. T. La, Ph. D.; David Sergio Napolitano, MSEE; Douglas E. Ives, MSME;** and **Larry J. Leifer, Ph. D.**

From the Spinal Cord Injury Service, PAVAMC: **Inder Perkash, M.D.**

Need — This project has as its goal the development of a wheelchair feedback controller intended to ease the control burden of the powered wheelchair user. Presently, most motor controllers are "open loop", i.e., the motor driving signal is not affected by the actual motion of the motor that is controlled. Because the motor controller does not independently react to disturbances in its environment (such as uneven ground, slopes, loss of traction), it is left to the vehicle operator to compensate for those variations from the ideal operating surface.

Another factor that impacts the driving burden experienced by the power wheelchair user is the fact that the controller's characteristics rarely acknowledge the unique abilities of the individual, due to the complexity and expense involved in manufacturing analog controllers with the appropriate signal conditioning capabilities.

Approach — In order to address these problems, the investigators decided to use microprocessor technology to perform the logic operations required to control an electric wheelchair.

The proposed path of development was, first, to model the physical characteristics of various types of wheelchairs mathematically for subsequent computer simulation of different types of control algorithms. Soon after the beginning of this project, the Palo Alto VA Medical Center acquired a Singer-Link Digital Image General System (DIGS). The DIGS will be used to perform the controls simulation and user preference portions of this investigation, in tandem with investigations of real wheelchair hardware.

The optics of the device provide a virtual image of the user's surroundings focused at infinity, with a 30 degree by 50 degree field of view. This, coupled with the use of the motion base included with the machine (to provide motion cues to the subject's vestibular system) provides the user with a compelling illusion of a real vehicle.

Status — The simulation portion of this project is presently awaiting the completion of building modifications to house the simulator at the Western Blind Rehabilitation Center. On the other hand, the development of the actual hardware for a micro-computer-based wheelchair controller has gone forth. It was decided early in the planning stage that a development path embodying "first principles" design methodology was preferable to the alternative of modifying currently existing wheelchair controllers to accept an add-on microprocessor.

The research group had plans to address the issues of efficiency and controller operating noise.

These considerations have had two results. First, the development of a very flexible and powerful controller logic development system with the capability of supporting virtually any control algorithm implementable on an 8-bit microcomputer. (A corresponding 16-bit system with hardware floating point capability is planned for this fall.)

The second consequence has been the development of a power amplifier using up-to-date technology. These are solid state "H bridge" power systems based on power MOSFET (Metal Oxide Semiconductor Field-Effect Transistor) devices which have become readily available in the capacities necessary only in the past few years. These devices have lower drive requirements than conventional bipolar transistors, resulting in a lower parts count, and thus, indirectly, greater reliability.They are able to switch faster than their bipolar counterparts (making possible efficient super-audible switching frequencies), and have smaller losses in the power range of common wheelchair cruising. These advantages combine to make them the device of choice in many state-of-the-art power control applications, and industry sources predict that prices and device losses will continue to fall in the future as the technology matures.

A test protocol for the evaluation of the various control algorithms has been outlined. Two groups of wheelchair "test pilots" will be used. The first will be an expert group, well-trained in the use of the simulator and familiar with the correspondence between the simulated and real vehicles. The second group will be composed of naive users, to insure that the preferences indicated by the first group do not reflect the so-called "test pilot syndrome" which is the ability of sufficiently expert pilots to operate even "uncontrollable" vehicles.

Two test sites are in preparation: the first is a simulation of a local shopping center used for mobility training, representative of a relatively benign environment. The second will be an obstacle course, including demanding maneuvering challenges (such as may be found while maneuvering in interior environments), as well as the classic geographic features used to test the mettle of a motor controller (e.g., compound slopes). The shopping center

data base obviously has a counterpart in the real world, making validation of the simulated environment relatively simple.

Pending — Refinement of the initial algorithms developed for the controllers will continue, and it is expected that one of these systems will be installed on a conventional castered wheelchair late this fall. Further, an interface between the wheelchair controller and the DIGS system remains to be built, so that the vehicle simulator can make use of the actual controller logic hardware and software built for the wheelchairs; this will facilitate the validation of the computer models developed for the vehicles involved in the study ■

MOBILITY AIDS
DECUBITUS ULCERS CUSHIONS

NIHR REC

TISSUE PRESSURE MANAGEMENT SYSTEM

Rebecca Williams
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Objective: To improve the quality of life and increase the independence of disabled individuals through the prevention of pressure sores.

Summary: For the last decade, the Rehabilitation Engineering Center at The Institute for Rehabilitation and Research (TIRR) has been directing its clinical and research activities towards the prevention of pressure sores. Through the cooperative efforts of physicians, therapists, engineers, orthotists, and nurses, a comprehensive program has been developed which has successfully reduced the recurrence of pressure sores over a 2-year period by about 80 percent. This program includes routine activities such as clinics, rounds, cushion and mattress evaluations, and patient education programs. The clinical activities have continued to expand to include pilot programs at other facilities, consultations for other hospitals and the Texas Rehabilitation Commission, and inservices to share the REC's research and clinical results ■

NIHR REC

ROLE OF REGIONAL STRESS AND STRAIN DISTRIBUTION IN THE PATHOPHYSIOLOGY OF DECUBITUS ULCERS

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Objective: To develop a mathematical model, capable of predicting changes in tissue pressure and blood flow, based upon radiographically obtained measurements of underlying bone geometry and interface pressure measurements.

Summary: The purpose of this project was to measure certain physiological variables necessary for construction of a first-approximation, predictive, computer simulation of the effects of external loading on a well-defined anatomical location. Such a mathematical model could be extremely useful in the evaluation of load-relieving devices and in the determination of prophylactic management regimes for high-risk decubitus ulcer patients.

Our hypothesis was that we could predict changes in tissue pressure and blood flow based upon radiographically obtained measurements of underlying bone geometry and interface pressure measurements. To accomplish this aim we devised experiments to (i) Make accurate measurements of interstitial tissue pressure, (ii) Correlate interstitial pressure with accurate measurements of interface pressure at different loads, (iii) Describe 3-dimensional force deformation in the tissues directly over a bony prominence with as much accuracy as possible, and (iv) Measure tissue blood flow, with and without loading, as accurately as possible. The past 3 years were used to collect and analyze this data ■

NIHR REC

PATIENT ACTIVITY MONITORING

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Objectives:

A. Develop unobtrusive instruments to monitor specific patient activities and/or devices over extended periods of time, both in hospital and following discharge.

B. Incorporate these instruments into clinical settings for routine use by the professional staff.

C. Evaluate the usefulness of these instruments as clinical tools.

Summary: This project is concerned with studying the activity and behavior patterns of patients with long-term physical handicaps. The major emphasis is to gain a more objective quantitative, and realistic description of what these patients actually do, during hospitalization and after discharge. It is assumed that this information could provide important insights, not currently available, into the rehabilitation process, and could help in the evaluation of programs and devices specifically developed to treat, ameliorate, and/or prevent pressure effects on tissues. The major conclusions of this study include:

A. Instrument-based longitudinal unobtrusive monitoring of selected specific patient activities over extended periods of time is both possible and practical in an inpatient rehabilitation setting.

B. Two relatively unobtrusive instruments — the Rest Time Monitor and the Sit Time Monitor — have been designed, fabricated, tested, and introduced into clinical settings for routine use by the professional staff and for use as research tools.

C. Longitudinal, objective, and quantitative measures of patient activities are useful clinical tools for assessing performance by individual patients and for comparing an individual's progress to standard performance curves.

D. The major findings of two research studies using the RTM showed that:

1. SCI patients who experience infection tend to spend significantly less time out of bed during the 3 weeks just prior to the onset of infection than do those patients who do not experience infections.

2. Fever and certain X-rays (especially IVP) are negatively correlated with time out of bed. These two events showed the highest degree of relationship to time out of bed among 17 selected events.

3. There is no evidence to support the hypothesis that the RTM can be used as an early-warning signal for thromboembolic problems or pressure sores.

4. Time out of bed is an important and convenient indicator of participation ■

NIHR REC

THE INFLUENCE OF ENVIRONMENTAL AGING UPON THE LOAD-BEARING PROPERTIES OF POLYURETHANE FOAM

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Objective: This study examines the possible contribution of environmental exposure to the breakdown of polyurethane foams that are used in the fabrication of wheelchair cushions.

Summary: The effects of environmental exposure upon the loadbearing properties of nine polyurethane foams commonly used for wheelchair cushion construction were studied. Test pieces with and without stretch cloth covers were aged in the open air in Houston over the period of April to October, 1982. The indentative resistance of each test piece was measured initially and at frequent intervals during the exposure period. Differences in hardness changes between covered and uncovered specimens were found to be not significant, with all foams displaying a sharp rise in indentation resistance within the first 2 weeks of aging, followed by a gradual decrease to an average hardness of 65 percent of the initial value over a 6-month period. The hardness changes were found to be strongly correlated with the density, thickness, and initial indentation of the test pieces. Foams of maximum density and minimum practical hardness are recommended for wheelchair cushion construction, to minimize the adverse effects of environmental aging upon the support properties of these devices ■

NIHR REC

THE INFLUENCE OF INFLATION PRESSURE ON THE EFFECTIVENESS OF AIR-FILLED WHEELCHAIR CUSHIONS

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Objective: The purpose of this study was to determine the relationship between interface pressure and the inflation pressure of air-filled wheelchair cushions. This information was intended to provide guidelines for further research in the design of a pressure indicator system that could be used to optimize the use of air-filled cushions.

Summary: Seating pressures were found to be dependent on the inflation pressure of the air cushion. This relative relationship for three commercially available cushions (i.e. RoHo, Gaymar Sof-Care, Bye-Bye Decubiti) is displayed in Figure 1. In all three cushions, underinflation produced a greater sensitivity than overinflation. This implies that overinflating the cushion is less dangerous than not inflating it enough.

A direct relationship between weight and internal pressure was determined; this may be expressed as: inflation pressure = .165 (weight in lb) + 4.5 mm Hg■

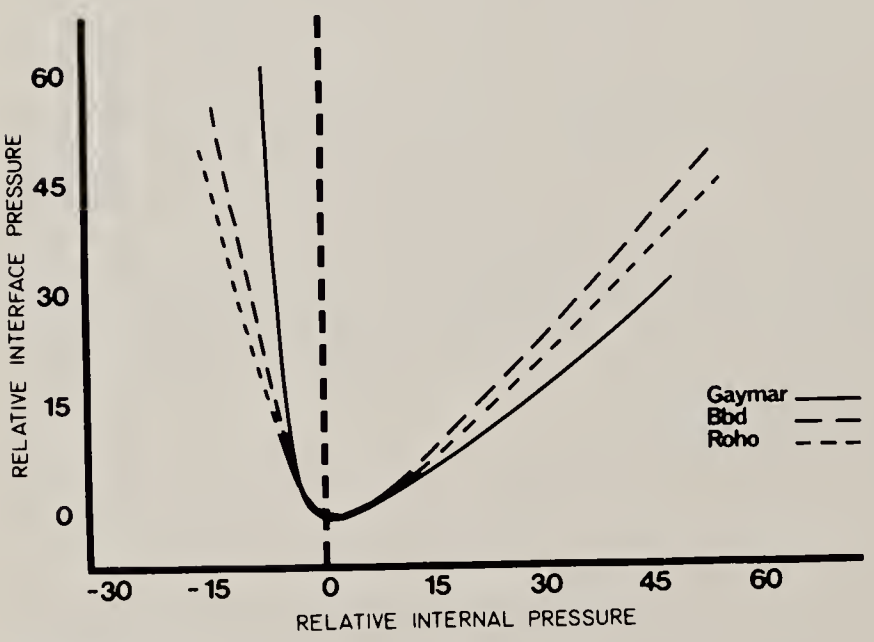

FIGURE 1
Pressure relationship for three commercially available cushions.

NIHR REC

THE RELATIONSHIP BETWEEN URINARY EXCRETION OF GLUCOSYL-GALACTOSYL HYDROXYLYSINE AND DECUBITUS ULCER FORMATION

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Objective: The primary objective of this study was to see if a temporal relationship exists between decubitus ulcer formation and urinary excretions of hydroxylysine glycosides. Specifically we wanted to see if there was any disproportionate rise in excretion of glucosyl-galactosyl-hydroxylysine preceding the formation of a decubitus ulcer.

A secondary but necessary objective was to develop a method for obtaining a complete amino acid profile, including the hydroxylysine glucosides, from urine samples.

Summary: The sample studied during this grant period consisted of 5 normal male control subjects and 10 male subjects with recent spinal cord injuries. The ages varied from 4 to 52 years and the subjects had no previous history of chronic diseases. The gylcoside content of the urine was evaluated on aliquots of 24-hour samples. The samples were also analyzed for creatinine content so that the results, when expressed as μ moles per gram of creatinine, eliminated variations due simply to differences in body size.

Although the ratio of glucosyl-galactosyl-hydroxylysine to galactosyl-hydroxylysine of the patients was not widely different from the ratio observed for the controls, the total increase in hydroxylysine glycoside excretion by the patients hints at a disturbance in the normal collagen turnover. None of the patients have developed skin ulcers to date. This would seem to be in line with the hypothesis that the ratio of glucosyl-galactosyl-hydroxylysine to galactosyl-hydroxylysine goes up prior to decubitus ulcer formation or stays roughly normal otherwise ■

VAMC PALO ALTO

SEATING SYSTEM FOR BODY SUPPORT AND PREVENTION OF TISSUE TRAUMA

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Rehabilitation Engineering Center
Children's Hospital at Stanford
Palo Alto, California 94304

The purpose of this project is to develop a total seating system that aids in the prevention of pressure sores and enhances the orthopedic management of the spinal cord injured. The centerpiece of this system is the Veterans Administration Seating Interface Orthosis (VASIO). The VASIO is a wheelchair seat cushion designed to redistribute pressures away from the osseous points and onto the more pressure-tolerant areas of the lateral flanks of the buttocks and the posterior thighs.

The version of the cushion for paraplegics (VASIO-P) was tested on 66 patients (57 thoracic, 9 cauda equina) and found to be effective in distributing pressures over the seating surface to levels well tolerated by the patients. Skeletal deformities were found to influence significantly the effectiveness of the cushion in distributing pressure to tolerable levels.

The VASIO-P is not recommended for use by quadriplegics who are unable to independently reposition themselves on the cushion. During the original study, it was found that those who were either malpositioned by an attendant or who became malpositioned through spasticity or other causes were often subjected to unacceptably high pressures. Failure of the patient to maintain his pelvis centered on the cushion typically results in abnormally high pressures beneath one ischial tuberosity and the contralateral trochanter.

A new cushion is being developed for quadriplegics. This cushion (VASIO-Q) is being designed to provide lower peak pressures than the VASIO-P and to compensate for malpositioning of the patient. Several design concepts are being clinically evaluated. Results are still preliminary but appear promising ■

MOBILITY AIDS
AUTOMOTIVE ADAPTIVE EQUIPMENT

NIHR REC

ADAPTIVE STEERING SYSTEMS

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In adapting conventional steering systems to the needs of drivers with severe disabilities, the required effort and range of limb motion may need to be reduced. This requires an increase in overall gain of the steering system — which reduces its margin of stability. Interactions between the driver and vehicle act as a closed-loop control system and have been studied using McRuer's "crossover" model.

A steering ratio that varies with steering wheel position and vehicle speed is desirable for the disabled driver. The study also revealed that the two most important parameters for vehicle stability are driver time delay and steering ratio. Guidelines for varying the steering ratio with vehicle speed and steering wheel position have been developed for a range of driver time-delays; they place a limit on allowable variations in steering ratio.

This variable steering ratio could be implemented with a microprocessor-controlled steering system. An experimental system has been built and tested. That system has not yet been mounted in the vehicle; however, it does show the feasibility of using a microprocessor to implement variable-ratio steering that can be adapated to the needs of a particular individual ■

NIHR REC

DESIGN AND DEVELOPMENT OF DEVICES AND SYSTEMS

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A new prototype of the sedan ingress-egress system has been made with the cooperation of Creative Controls, Inc., a potential manufacturer. The system consists of a double-pivoted power-operated arm attached to the car floor. This arm supports the wheelchair and its occupant while the wheels

FIGURE 1
Wheelchair and occupant in position to enter vehicle. Wheels are retracted by ball-screw actuator.

retract for rotation into the driver's position (Fig. 1, 2). The car door is also opened and closed by the arm actuator. This system is presently installed in an Oldsmobile Omega and will soon be installed in a 2-door Dodge 400 sedan. These vehicles were donated by General Motors and Chrysler Corporation, respectively.

As the system development is transferred to the manufacturer, the UM REC is studying the potential use of the new minivans scheduled to begin reaching the market this fall. Chrysler Corporation has made a full-sized minivan model available for the analysis of entry systems and wheelchairs compatible with this vehicle. A wood and plastic wheelchair model with a lowering seat allows us to study an occupant entering this vehicle as the driver or as a passenger (Fig. 3, 4). This study is expected to continue as these smaller vans become available ■

FIGURE 2
Wheelchair is being rotated into driving position by supporting arm.

FIGURE 3
Reclining chair enters minivan model via raised ramp.

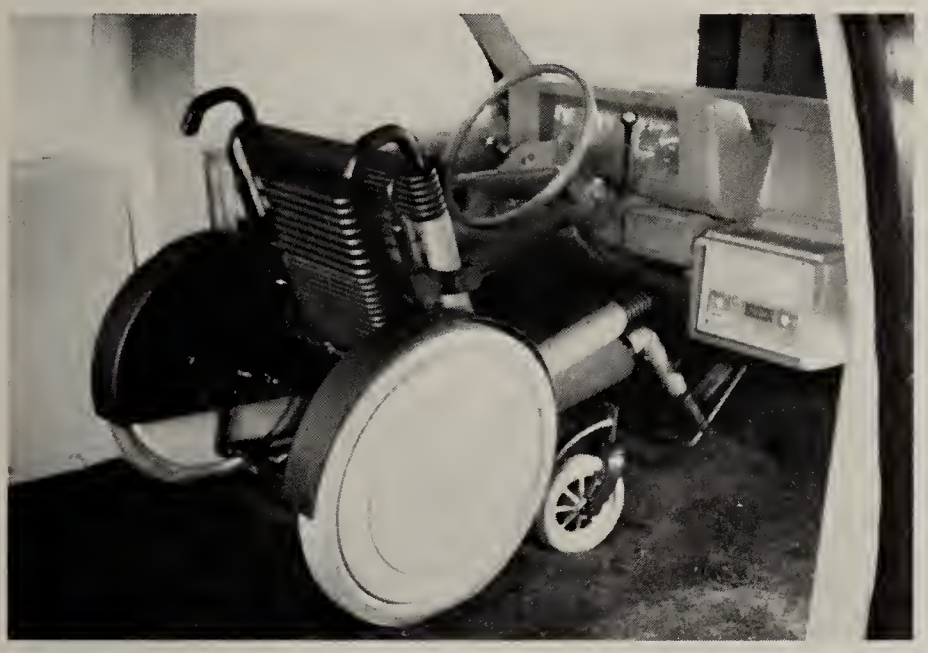

FIGURE 4
Model Wheelchair in driving position in minivan model.

NIHR REC

ASSESSMENT OF PERFORMANCE CAPABILITIES OF THE DISABLED DRIVER

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A part-task driving simulator has been used in an ongoing program for the training and evaluation of persons with perceptual and psychomotor disabilities. Decisions based on simulator evaluations need to be validated by testing driving performance on the road, and an instrumented automobile was used to evaluate the same 8 persons who had previously been evaluated on the simulator.

A Dodge Omni with hand controls was used for on-the-road testing. A compact accelerometer was mounted on the transmission for the recording of longitudinal and lateral acceleration. A force transducer was mounted to record the frequency and severity of braking action. Potentiometers were mounted to record steering control. The driving course was essentially the same as the one previously developed by the UM REC for use in the remediation of perceptual/cognitive deficits.

Each subject was given a trial session. This was followed by a data collection session on another day. On sebsequent but not necessarily consecutive days, two more trial sessions were held, followed by a final data-collection session.

A record was kept of lateral and longitudinal acceleration, steering control deviations from a centerline, the average and maximum values of the linear travel of gas and brake pedals, and of the subjective observations made over the driving course. Testing is in progress to determine the correlation between simulator and actual driving performance ■

NIHR REC

REMEDIATION OF DEFICIENT DRIVING SKILLS IN PERSONS WITH BRAIN DAMAGE

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The purpose of this study was to develop and validate a system for teaching driver readiness skills to persons with brain damage so that they could proceed to a formal on-the-road disabled driver education program. A study was designed to test the hypothesis that systematic training utilizing a small motorized vehicle (modified AMIGO wheelchair) would have a positive effect upon driving an automobile among the population with acquired brain damage.

Twelve brain-injured subjects and four non-brain-injured subjects completed the evaluation and training protocol. The protocol included (i) a pre-training intraffic driving test, (ii) a pretraining cognitive/perceptual evaluation, (iii) a second pretraining intraffic driving test, (iv) a second pretraining cognitive/perceptual evaluation; (v) eight 2-hour training sessions with the modified AMIGO wheelchair, (vi) posttraining intraffic driving evaluation, and (vii) a posttraining cognitive/perceptual driving evaluation.

Preliminary results reflecting the driver educator's rating of each subject indicated that nine of the brain-

injured subjects showed improvement of at least 1 rating point (on a 5-point scale) with 2 improving ½ a scale point and 2 remaining the same. In addition, three participants improved significantly to be recommended to take a state driving test ■

NIHR REC

REMEDIATION OF PERCEPTUAL/COGNITIVE DEFICITS: EFFECTS ON DRIVING PERFORMANCE

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The driving performance of persons with brain damage is directly related to the extent of their perceptual damage. Specifically, persons with brain damage who scored well on certain perceptual tests tended to show good driving performance. These findings suggest that therapeutic techniques capable of improving the impaired perceptual skills might also improve driving performance.

This hypothesis received tentative support in our pilot study and was more thoroughly tested in the present study. Specifically, we have investigated (i) the modifiability of perceptual deficits of persons with brain damage by simple paper-and-pencil techniques, and (ii) the effects of such techniques on subsequent driving performance.

Eight subjects participated in the study. Standard perceptual tests were used to evaluate pre- and post-training perceptual capabilities. Driving performance was evaluated on a specially designed and validated intraffic driving course.

Training exercises were designed to foster improvements in visual scanning, directed eye movements, spatial perception and discrimination, figure/ground differentiation and visual imagery. Each subject received a total of 8 to 10 hours of individualized training.

The results indicated that (i) perceptual skills improved following the perceptual training; (ii) the training was associated with improved driving performance; and (iii) the degree of improvement in driving performance was directly related to the degree of perceptual improvement ■

NIHR REC

WHEELCHAIR RESTRAINTS

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The UM REC occupant protection project is aimed at studying the problems and issues of providing effective wheelchair and occupant restraint for severely disabled persons and at working toward the development and implementation of effective devices and solutions. During the past year, a prototype wheelchair add-on restraint system and head restraint (Fig. 1) were developed and tested at the 30 mph/20G crash-severity level. The performance was excellent, and design efforts are currently underway to modify

FIGURE 1
Prototype wheelchair add-on restraint system with head restraint.

this initial design so that it is easily manufactured and fitted to wheelchairs, and will be acceptable to the user. The testing of commercially available and prototype restraint systems continues at the University of Michigan Transportation Research Institute.

UM REC personnel continue the information dissemination process about wheelchair restraints through formal presentations and articles. Reports are distributed to interested persons, and slide presentations and films are often loaned. Trips to the field to followup previous correspondence provide a useful and sometimes necessary exchange of information ■

NIHR REC

INTERFACING DISABLED DRIVERS TO VEHICLE SECONDARY CONTROLS

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Many disabled drivers have the functional capabilities to operate the primary controls (steering, throttle, and brake) of a vehicle. Some of them may have few if any functional capabilities remaining for operation of secondary controls in a safe and practical manner.

The primary purpose of the interface laboratory is to develop methods and guidelines for interfacing disabled drivers to secondary controls in a motor vehicle. A computer secondary-control simulation system is being developed to evaluate disabled persons. Results of testing will be used to establish general methods and guidelines ■

VAMC ATLANTA

DRIVER SITUATION SIMULATOR

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This system is intended to be used to evaluate disabled-driver controls presently on the market, to evaluate a disabled driver's ability to use such controls quantitatively, to provide a tool for disabled driver training, and to be a research tool for new control development.

Progress — The first system is operable, using a modified arcade game called "Grand Prix", and is implemented on an Apple II Plus microcomputer. Newer software is now being written with better interactive graphics. The control platform or base is a wooden mock-up using real controls coupled electronically to the computer. The system has had a good reception among therapists, researchers, and disabled users. (This design was a winner at the 1982 RESNA Student Design Competition.)

The software package is approximately 30 percent complete at this time and the hardware design is proceeding on schedule. The system has had considerable user and therapist input to date and has had considerable approval even in its primitive form.

Future plans — Plans are to continue with software and hardware development to arrive at a driver-situation simulator in 9 months. This will be completed at the Atlanta Veterans Administration Medical Center with the considerable assistance of medical personnel and user input ■

ADL AND RECREATION

NUREP

MODULAR MOUTHSTICK SYSTEM

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A mouthstick system has been designed and developed by NUREP and the Rehabilitation Institute of Chicago, Occupational Therapy Department, which incorporates a combination of desirable features based on a review of existing literature and examination of commercial systems. This lightweight mouthstick system enables users to independently change a variety of appliance tips and adjust shaft length for performing academic, vocational, and avocational activities.

Components of this modular mouthstick system which could be manufactured in kit form include the following:

1. A custom mouthpiece (to be fabricated by dentist).
2. A telescoping shaft consisting of a fiberglass arrowshaft which can be slid in/out of an aluminum tube by the user. To extend the shaft, the user pulls it out like a telescope by a tab on the distal end; the shaft is shortened by pressing the distal end against a fixed object.

3. A shaft/appliance-holder tube-latching mechanism consisting of a round-head screw which holds a rubber "O" ring against a threaded insert; the insert is bonded into the distal end of the arrowshaft.

4. Three appliance-holder tubes fabricated from Delrin plastic.

5. A mounting system consisting of an aluminum bracket (which positions the appliance holder tubes) attached to an adjustable camera clamp.

A custom-fit mouthpiece is fabricated using an aluminum bite fork which is covered with a pliable football mouthguard material. The dental impression is obtained by pressing an articulated plaster model of the teeth into the mouthguard material which is warmed and softened.

The mouthstick system is now commercially available without the telescoping shaft and mouthpiece ■

VA RR&D CENTER PALO ALTO

DEVELOPMENT OF RECREATIONAL BICYCLES FOR THE DISABLED

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VA Rehabilitation Research and Development Center
Palo Alto VA Medical Center, Palo Alto, California 94304

Need — As a recreational activity engéndering both physical and emotional vitality, bicycling is particularly appropriate for an individual facing barriers in mobility and participation.

Approach — Our approach has been to continue the development of the arm-powered bicycle, called the Handbike (previously called the Para-Bike), and begin development of the Handbike Tandem for disabled and able-bodied individuals to ride together. Development has been carried out on a prototype/evaluation basis.

Status — Four prototypes of the Handbike have been completed to date. The latest version features adjustable side casters which touch down at desired lean. They can also be fastened down to hold the Handbike upright for four-wheel maneuverability indoors. A folding crank tower has been added to facilitate transfer to and from a wheelchair.

Development of the Handbike is now complete, and a company has begun production.

A first prototype of the Handbike Tandem has been built and is currently being test-ridden. Like the Handbike, the Handbike Tandem is a bicycle, with lean-adjustable side casters. It features a Handbike in the front and a standard foot operated bicycle in the back. With dual steering, the Handbike Tandem may be ridden as a single-rider vehicle from either the front or the back.

Pending — The design of a second prototype of the Handbike Tandem is in progress. Because of the success of the first Handbike Tandem prototype, it is expected that a second prototype will complete the pre-production development ■

TREATMENT AND TRAINING

LIBERTY MUTUAL, NIHR, SWEDEN

TOPICAL ANESTHESIA: A NEW TREATMENT METHODOLOGY FOR PATIENTS WITH STROKE

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Application of topical anesthesia to the skin has been used in our laboratory in the past 3 years for the purpose of improving the control of movement in patients affected with spasticity. Desensitization of cutaneous receptors has been found to modulate the excitability of selective motoneurons so that discrete active movement patterns can be performed. Utilization of these active movements in functional activity requires a long-term process of relearning, as well as reprogramming of the movements executed by the nervous system. Possible accessory neural pathways and switching mechanisms could be activated in the central nervous system which could compensate for the loss at the site of the lesion.

The short-term effect of application of topical anesthesia has been studied on 70 patients afflicted with spasticity of different pathologies.

During the past year, a new force platform with computer-assisted measurements of the forces applied to the feet was installed and is employed in our

experiments. Stabilograms (degree of the center of gravity sway during static standing) are being recorded in stroke patients before and after application of topical anesthesia to the lower limbs. Furthermore, photoelectric light cells have been constructed in order to accurately measure the speed of limb movement (either during walking cycles or during rapid repetitive movements of the arm and leg).

Preliminary analysis of the gait data demonstrated a substantial decrease in the asymmetry between the lower limbs during the walking cycle. Substantial increases in angular displacement of the hip, knee, and ankle joints, as well as smoothness and speed of movement, were also noted after a 1-month period of treatment with topical anesthesia. Computerized axial tomography records (CAT scans) revealed that patients with lesions in specific areas of the brain realized the greatest amount of improvement in their movement capability. Again, as previously reported, no measurable improvements were noted after a 1-month period of treatment with a placebo spray.

During the past year, we made two additional noteworthy observations. In one of our subjects, functional recovery has continued to increase for 3 years after termination of the treatment program. Such progress is not usually seen in similar patients who have received different treatments. The second interesting observation was made on a patient with chronic head injury (18 years) and on a stroke victim (12 years). In both cases, immediate improvements in their active movement patterns were noted when the topical anesthesia was applied.

Recently, we have begun to use another topical anesthetic (10 percent Xylocaine). Preliminary observations indicate that it should provide even more dramatic results than with 20 percent Benzocaine ■

LIBERTY MUTUAL, NIHR, SWEDEN

TOPICAL ANESTHESIA: POSSIBLE USEFULNESS IN PATIENTS WITH CEREBRAL PALSY

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Cerebral Palsy is a major congenital disorder which is manifested by spasticity, flaccidity, ataxia or athetosis. Patients with cerebral palsy are usually afflicted with one or more of these motor control disorders. The use of topical anesthesia in the improvement of motor control of spastic-type cerebral palsy has been tested in six patient (four children and two adolescents). Videotape analysis of active movement patterns were recorded before and 30 minutes after the application of topical anesthesia (20 percent verify the short-term effect of topical anesthesia on muscular activity). The range of movements of the lower-limb joints was measured in one patient using conventional methods. Electrophysiological and gait studies were also performed on two patients to correlate the physiological and functional changes in the neuromuscular system after desensitization of the skin.

Preliminary results demonstrated a rapidly manifested short-term increase in joint mobility and reduction of muscular stiffness, as well as an increase in active movement patterns of the upper and lower limbs, after application of topical anesthesia. These results varied in degrees among different patients. Gait analysis demonstrated an increase in stride length and walking speed as well as a shift of the temporal component of the gait cycle toward normalcy. Subjective observation by the patients and their guardians also indicated an increase in the active movement pattern of the lower limbs ■

LIBERTY MUTUAL, NIHR, SWEDEN

TOPICAL ANESTHESIA: POSSIBLE USEFULNESS IN PATIENTS WITH NEUROGENIC BLADDER

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The application of topical anesthesia in the control of neurogenic bladder for patients with spinal cord injury has continued in the past year. These patients have considerable difficulty in voiding their bladders due to their inability to voluntary relax the muscles which control the opening of the bladder.

Two patients with spinal cord injury at T6 and T12 were tested. The patients were catheterized with a specially designed trilumen catheter under aseptic conditions. The intrabladder and intraurethral pressures were measured during gradual infusion of the bladder with a radio-contrast solution (Furandantin). The entire urodynamic study was monitored with an image intensifier and was videotaped. The myoelectric signal of the external urethral sphincter muscle

was also recorded before and 30 minutes after application of topical anesthesia to L1, S2, and S3 dermatomes near the scrotum and the upper part of the thigh. Patients with assynergic bladder (simultaneous contractions of the detrusor bladder and sphincter muscles) were selected for the study.

Experiments are in progress to identify which of the various topical anesthetics is the most effective in decreasing the synergistic muscular contractions in patients affected with spinal cord injury. Preliminary results are encouraging. Mapping of the skin areas which control the bladder synergy is foreseen ■

VA RR&D CENTER HINES

AN ENHANCED UNDERSTANDING OF THE SPINAL PHARMACOLOGICAL SUBSTRATE FOR THE NEURAL MECHANISMS UNDERLYING BLADDER DYSFUNCTION AFTER SPINAL TRAUMA

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The precise underlying neurological cause for bladder dysfunction after cervical, thoracic, or lumbar spinal trauma is unknown. Recent evidence from two different areas suggests that a peptide called enhaphalin, that is produced within the body and that acts much like morphine, may play a key role: (i) patients who have undergone injections of morphine-like compounds onto the spinal cord for pain relief often exhibit problems in urination; and (ii) morphine-sensitive receptors have been found in that part of the sacral spinal cord that controls urination. We hypothesize that a morphine antagonist (i.e., a competitive blocker) like naloxone might prove extremely beneficial in helping restore bladder function if applied to the spinal cord just after trauma. In fact, naloxone given systemically (i.e., IV) does appear to have a helpful effect on restoring both skeletal muscle and bladder function in the long term spinal patient.

Our results to date indicate that in six normal (i.e., uninstrumented and awake) dogs, the bladder volume at which urination began was raised significantly after spinal morphine, and that this change was reversed by spinal administration of naloxone. Such changes in micturition threshold that follow spinal morphine injection resembled very closely the changed thresholds that we later saw following spinal transection in these dogs. Further, there was a reduction of micturition thresholds in two of the three acutely transected dogs given spinal naloxone. While further experimentation is necessary, these preliminary results do highlight a possible role of the endogenous opiates in producing bladder dysfunction after spinal trauma. We are now extending these pharmacological studies to our chronically instrumented animals ■

VA RR&D CENTER HINES

VOICE-OPERATED APPLIANCE CONTROL AND SWITCH

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Recent advances in voice recognition technology have provided low-cost integrated circuits capable of speaker-independent recognition of up to 16 words. This center has developed two devices to demonstrate the usefulness of this technology to disabled people.

One device is called the voice-operated appliance control (VOAC). The VOAC allows its user to operate up to 256 electrical devices with three simple voice commands: "go ahead," "search" and "stop." "Search" causes the VOAC to sequentially display its three basic control modes: "all on," "all off," and, "select." When the desired mode is displayed, it is selected by saying "stop." The user executes the mode by saying "go ahead." Selecting "all off" or "all on" will turn all units off or on. Selecting "select" allows control of individual units. "Faster" and "slower" control the display rate at all times.

In the select mode, the VOAC sequentially displays the numbers of available units. A unit is selected by stopping the display when the unit's number appears. When the unit has been selected, the VOAC sequentially displays functions available for that unit. Possible functions are "on," "off," "bright," "dim," and "momentary." The latter will turn a unit on until the user says "stop." As before, functions are selected by stopping the display and saying "go ahead."

The voice-operated switch (VOCALINK) is designed to replace the two-position switches used to activate many electrical devices for disabled people. These switches can be breath-activated (sip/puff) or operated by small movements of the lips, tongue, forehead, arm, leg, or foot.

The two switch positions are replaced with the words "go ahead" and "stop." These words can be used alone or in combination to control most devices.

A third word "repeat" can be used to repeat the basic control words or word combination. This feature is particularly useful with devices that use scanning, such as TV remote controls.

VOCALINK consists of two separate units: a voice-recognition module and a control module. The voice recognition module determines what word has been said, and transmits a code for that word to the control module. The control module interprets the code and activates one of two electronic switches ■

VA RR&D CENTER PALO ALTO

NERVE REPAIR AND EVALUATION

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Need — The lack of objective methods for assessing the extent of nerve injury and regeneration compels physicians to rely on subjective criteria in making clinical decisions regarding type and timing of care; it also hampers the search for better methods of nerve repair. These are significant problems because present methods of peripheral nerve repair, even those employing modern microsurgical techniques, rarely result in regeneration sufficient for full functional recovery. Two microsurgical repair methods, epineurial suture (ES) and fascicular suture (FS), are in common use. Neither method has been shown to be clearly superior.

The invasion of scar tissue into the repaired nerve is considered to be a significant barrier to regeneration. A new technique, termed tubulization, utilizes a tube or wrap of biocompatible membrane to re-oppose the ends of severed nerve and to shield the regenerating axons from the ingrowth of scar. This method may have other advantages in that it produces total circumferential alignment of the nerve or fascicle, is relatively noninvasive, and contains (and possibly directs) the sprouting axons. The materials used for these repairs have included tubes and membranes of vein, Silastic, fibrinogenic material, collagen, and polyglycolic acid (PGA, adsorbable suture material).

The enhancement of regeneration through the development of more sophisticated surgical alignment techniques, the application of pharmacological agents, or the use of other modalities has been hindered by the lack of quantitative means of monitoring the regenerative process and evaluating the extent of functional reinnervation. Preliminary results of a parallel investigation of surgical repair techniques and methods for evaluating functional regeneration are presented.

Approach — Histological techniques are the most frequently used quantitative methods of evaluating the extent of regeneration following repair. The fiber diameter histogram (FDH) is obtained by determining the number of axons within specific cross section diameter ranges; the count:diameter data are normally presented in histogram form. The FDH is used to evaluate the number and maturity of the regenerated axons. Longitudinal architecture of the axons at the repair site is a more qualitative means of evaluating repair technique success.

Histologic assessments often correlate poorly with the functional conduction properties of the regenerated axons; it is for this reason that the distribution of conduction velocities (DCV) approach has been used to evaluate repair methods. The DCV is the electrophysiologic counterpart of the histologic FDH. It is typically plotted as a histogram, showing the relative contribution to the compound action potential (CAP, related to the number of axons) from axons conducting in specified velocity classes. The DCV provides information on the conduction properties of the entire population of fibers within the bundle, whereas classical measures of maximum conduction velocity (calculated from the waveform onsets) and CAP amplitude primarily represent only the fastest fibers within the bundle.

The DVC of mixed nerve (both sensory and motor) can be obtained by the "deconvolution" of two CAPs recorded at sites separated by a known distance (2CAP). The deconvolution technique can be applied to two muscle action potentials (MAP) evoked by stimulation at two sites along the nerve to derive the DCV of motor axons (2 MAP). The motor DCV can also be obtained by a collision neurographic technique (CMAP). This technique employs the interaction of two CAPs evoked by carefully timed stimuli to limit conduction to a small range of conduction velocities. These DCV techniques have also been applied to humans for the evaluation of perhipheral neuropathies.

Status — The median and ulnar nerves of 13 primates, Macaca Fascicularis (Crab-eating monkey), were used as the model for investigating repair techniques.

The nerves were exposed at the wrist and then transected. The nerves were then repaired by the ES method (14 nerves), or by the FS method after dis-

section to the fascicular level (16 nerves). Tubulization was done at the fascicular level (FT) using split PGA tubes (17 nerves). Five nerves were not repaired, a 1.0 cm segment being removed and submitted for preoperative histologic evaluation.

Preliminary analysis of the electrophysiologic data from a small number of primates showed no significant difference in regeneration between the three repair methods. There was a significant difference between the repaired and unrepaired nerve regeneration. Histologic evaluation showed generally better longitudinal architecture of axons at the repair site of nerves repaired with the FT technique than those repaired by other techniques. FDH evaluations have not been completed at this time.

Pending — Pending are FDH analyses of all nerves and an analyses of remaining DCVs. Also pending is a study of the effects of tension on regeneration in the same animal model. Due to the lack of a clearly superior surgical repair method, other modalities specific to the regenerative process, such as pharmacological agents, will be investigated. To aid the surgeon in determining the course of treatment, methods for evaluating the extent of injury, preoperatively and intraoperatively, are being developed to allow the full potential of the new repair methods to be realized ■

VA RR&D CENTER PALO ALTO

A LEARNING LABORATORY FOR THE DISABLED

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It is hypothesized that an interactive learning lab that provides disabled users with independent access to video information will be a useful tool in rehabilitation programs. Key features of such a system will be its accessibility to users with varying capabilities (from high-level quadriplegics to able-bodied), its capacity for abundant video information, and the quality of giving users both real and perceived control of the system. Additionally, it should be able to test the users on material presented and save that data for interpretation or studies.

Design of such a system presents three major challenges. The first is to design a "library" system for the video material.

The second design challenge is to specify an interface, or set of interfaces, that allows all users to access the system as naturally and efficiently as possible at their level of ability.

Finally, the system must be designed to be compact and portable, yet at the same time provide isolation for the user.

Status — A concept-proving prototype Learning Laboratory (LLab) has been designed and constructed using an Apple II+ computer, a Panasonic VHS video-tape player, and a Scott Instruments Shadow/VET voice recognition unit. This prototype will be used in the Palo Alto VA Medical Center Spinal Cord Injury Service to provide both technical and clinical feedback for the design of the next-generation system.

Although documented testing has yet to begin, several important facts have already been learned about the system. First, only a very small body of knowledge exists in the field of interactive video education. It is apparent that this prototype will serve as a test-bed for developing good interactive video lesson planning techniques. Secondly, there are few high quality, up-to-date video tapes available dealing with spinal cord injury. Finally, since the system's computer is able to record large amounts of data about each session, the LLab is emerging as a powerful research tool. Studies ranging from interface use to the psychological impact of different educational styles can be carried out with the LLab ■

NIH MUSCULOSKELETAL

SKELETAL MUSCLE ADAPTATIONS INDUCED BY TRAINING

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This project is concerned with skeletal muscle function, energy metabolism, and biochemical adaptations induced by exercise training. Particular attention is given to the response of the different skeletal muscle fiber types, since each fiber is characterized by distinct biochemical and physiological properties. Further, these distinctions probably have a direct influence on the adaptive responses induced within each fiber type by exercise training.

Aspects of adenylate metabolism and the purine nucleotide cycle in working muscle and during recovery will be evaluated. This evaluation will include an assessment of the factors that are important in the activation of AMP deaminase in vivo and the amine source for adenylate resynthesis following

intense muscle use in rats. The involvement of certain amino acids in energy metabolism will be evaluated during steady-state muscle use with an isolated perfused hind-limb preparation. The energy contribution of branched-chain amino acid oxidation, the extent of oxidative deamination of glutarate, and the mode of amine nitrogen elimination from the working muscle will be determined.

A major adaptation induced in skeletal muscle by training is an increase in the capacity for ATP provision via oxidative metabolism. The impact of this adaptation on the above processes will be made. In addition, investigations with muscle stimulated in vitro will be performed to explore the physiological significance of the adaptive changes induced by training ■

NIHR REC

FACILITATION OF VOLUNTARY CONTROL USING TRACKING TASK TRAINER

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Introduction — A microprocessor-controlled tracking task trainer has been developed at this institution for training reciprocating motion. Results recently compiled on a study over the period of a year, for a group of 20 subjects selected from the outpatient population at Rancho, reveal significant improvement in functional ability for those patients in the study receiving regular tracking-trainer treatment. Functional improvement was measured as an increase in the number of turns of a wrist-motion task designed to test reciprocating motion ability, and by two indices generated by the tracking trainer: "ONTIME," the amount of time that the patient correctly tracks the target during a task, and "ERROR SCORE," an integral of the tracking error during a task.

Methodology — The Tracking Trainer was developed using a Digital Equipment Corp. MINC 11/23 computer for software design, and a Tektronix 8001 microprocessor development lab for hardware design and software/hardware integration. The system presents a randomly moving target on a video monitor for a patient to track by means of an electrical goniometer placed about an affected joint. The Trainer can be used for both coordinated motion treatment and measurement of patient motor-control progress. The device is based on the Motorola 6800 microprocessor and has many control options available to the therapist using the device. These options include target shape and motion parameters, treatment times, and patient compensation parameters.

Twenty hemiparetic patients were selected from the patient population at Rancho Los Amigos Hospital.

Results — Results of the study showed significant differences between the Study and Control groups.

For the Control group, a 17.9 percent increase in ONTIME was seen as compared to 43.9 percent for the Study group. Correspondingly, there was a decrease of only 13.1 percent in the ERROR SCORE for the Control group while the ERROR SCORE for the Study group dropped 32.6 percent. In the functional test, the Study group improved an average of 3.3 turns in 45 seconds while the Control group improved only 0.7 turns. Comparing the two measurement techniques to each other (the ONTIME and ERROR SCORE versus the turning test) it is seen that similar ratios exist when data from the Study and Control groups are compared. For the turning test, a ratio of approximately 4.7 to 1 for the Study group is seen compared to the Control group and for the Tracking Trainer indices the ratio is approximately 2.5 to 1. The progress of a Study and a Control patient was compared over the course of three weeks for ONTIME and ERROR SCORE.

Conclusion — It has been shown that the use of the Tracking Trainer can improve functional ability in the control of a reciprocating motion task ■

NIHR REC

THE CONTROL EVALUATION-AND-TRAINING KIT

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The Control Evaluator and Training Kit (CETK) is a portable microprocessor-based device used as a tool for systematic, quantitative assessment and training for using controls with assistive devices. This tool is used to collect comparative information regarding a disabled person's ability to control assistive devices used for mobility, communication and environmental control.

The Control Evaluator and Training Kit is designed to provide to the professional community working with disabled individuals a tool to evaluate and train

for control of assistive devices. Used with the publication "A Guide to Controls: Selection, Mounting, Applications," decisions could be made regarding a person's ability to use standard controls and whether specialized help would be needed to identify an appropriate control.

Quantitative evaluation is needed to compare control site/control combinations identified during an initial evaluation to develop a list of controls, rank-ordered according to optimal use by the client. The measures include the client's speed and accuracy in activating the control, and the degree to which the performance with a control can be repeated over time, i.e., from week to week.

The measurements that are monitored with the CETK are trial time, frequency (activations/sec), latency (reaction time to either release or activate a switch), duration (length of activation) and performance errors. These measurements are used to collect data regarding speed, accuracy, fatigue, and repeatability.

Based on these performance measurements, each of the control site/control combinations initially determined to be potentially useful are rank ordered. From that list, the user and the examiner may select according to the device to be operated and according to the user's preference, based on experience with the control using the CETK.

Other current research projects in the communication and control area include:

- Use of speech recognition as a method of controlling assistive devices by individuals with unintelligible but consistent speech
- Applications of alternatives to keyboards
- Development of systems to increase opportunities for people with physical limitations to have access to computer systems
- A comparative study of control and display principles which affect efficient use of communication aids for severely physically disabled individuals ■

VAMC BRONX

CAPUCHIN MONKEYS AS AIDES FOR QUADRIPLEGICS

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Pilot project research has shown that capuchin monkeys have the potential to be as valuable to high-level quadriplegics as guide dogs are now to the blind. Current goals and the progress made on each is as follows:

1. The standardization of training procedures for teaching monkeys a basic repertoire of skills. Approximately two-thirds of the training procedures used in teaching a basic repertoire of skills have been standardized, and are described in a 100-page illustrated training manual. By following the instructions in this manual, inexperienced college students have successfully trained naive monkeys with only occasional help from a training supervisor.
2. The redesign of equipment which allows the disabled user to direct, reward, and punish his animal helper. The shock/buzz remote-control harnesses used to discipline the monkeys have been reduced in size and weight. A variable-level shock control has been added to the unit. Powder reward dispensers which frequently clogged have been replaced with inexpensive manually operated liquid-reward dispensers.
3. A directory of new skills which can be taught to monkeys. Only four new behaviors have been added to the basic list. It seems as if most high-level quadriplegics share many of the same basic needs.
4. Placement of 3-4 monkeys per year with new owners. Three additional placements have been made since June of 1982. Feedback has resulted in a better understanding of the type of situation in which these animal aides can be of most value.
5. The evaluation of all placements. A proposal is being prepared for submission to the VA Prosthetic and Sensory Aids Service requesting an independent evaluation of simian aides.
6. A cost/benefit analysis for the disabled recipient and the health care system. Preliminary results indicate the financial and psychosocial benefits derived from owning a simian aide outweigh the costs. A more formal analysis awaits data that will be collected during the independent evaluation.
7. An analysis of the type of organization which can train and place simian aides on a larger scale. A detached outline of an organization has not only been drawn up, but established. Helping Hands: Simian Aides for the Disabled, Inc. was incorporated in New York State in October of 1982 as a nonprofit organization ■

NIHR REC

IMPROVING THE VOCATIONAL PROSPECTS OF THE SEVERELY DISABLED

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Projects of the Center — The following report covers the period from July 1, 1982, to June 30, 1983.

Evaluation Project — The efforts of the Evaluation Project relate primarily to the Available Motions Inventory (A.M.I.). The latter is an evaluation system which identifies physical competencies as they relate to refining the utilization of the data derived from the A.M.I. Don Malzahn is Director of this project.

Independent Living Project — This project of Rehabilitation Engineering Center has consistently supported the main charge of the Center which is occupationally related. Employed disabled persons must have schemes whereby they can operate independently in their home setting and for personal care at the workplace.

Aspects of independent living which have been addressed this grant year are requirements for independent access from home settings, requirements for independent living in kitchen and bathroom areas of the home, and availability of commercially produced items to meet such needs. Elmer Hoyer is Director of this project.

COS Unit Project — This is an experimental vocational diagnostic and training project. Some aspects which have been researched this grant year are the effectiveness of posture seating, and worksite modifications in enhancing work performance. In conjunction with the evaluation project, analysis was made of work-related skills having value in predicting subsequent work performance. Marcia Perry is Director of this project.

Technical Brief Publication — A Tech Brief is published periodically by this Center. It features descriptions of devices which alleviate limitations of disability in worksite or daily living settings ■

DIAGNOSTICS AND INFORMATION

NIHR REC

A COMPUTER-AUTOMATED SYSTEM TO ASSESS FUNCTION OF HANDICAPPED INDIVIDUALS

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For more than two decades, members of this group have been developing and evaluating batteries of tests for assessing functions of handicapped individuals. Their most recent test battery is computer-automated and includes assessments of mental alertness, vision, hearing, steadiness, reactions, sensations, speed and coordination, posture, selected activities of daily living, strength, and fatigue.

The site of this work, the Neurofunction Laboratory at the Health Science Center, is now being expanded to include assessments of gait, range of motion about various body joints, and propriopception; existing tests are being improved; and the laboratory's utility as a device for assessing the functions of handicapped individuals is being evaluated. Patient groups will include those with spinal cord injuries, brain injuries, stroke, adult cerebral palsy, spina bifida, back disabilities, amputated limbs, multiple sclerosis, Parkinson's disease, Huntington's disease, peripheral neuropathies, tardive dyskinesia, and myasthenia gravis. Studies will also be done to determine the reliability of test measures, and the effects of age, gender, learning, and handedness in normal individuals. Results of studies with normal individuals will be used to establish a data base from which patient data can be scored as a percentage of normal function, adjusted for age and gender.

After applicability to specific patient populations has been determined, the Neurofunction Laboratory will be used to evaluate the effectiveness of new drugs, surgical procedures, and rehabilitation treatments, as well as to assist in patient diagnosis and disability evaluation.

Primary funding for this effort comes from a grant recently awarded by the National Institute of Handicapped Research for the purpose of establishing a

Rehabilitation Engineering Center for functional assessment of the handicapped. The grant went to a consortium of four institutions: the University of Texas at Arlington, the Dallas Rehabilitation Institute, the University of Texas Health Science Center at Dallas, and the Dallas Rehabilitation Foundation. The consortium was organized by investigators with an interest in rehabilitation engineering ■

NIHR REC

QUANTITATIVE ASSESSMENT OF MUSCULAR FATIGUE

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Experiments to determine how handedness, gender, and force level relate to the process of localized muscle fatigue have been completed over the past year. A total of 40 normal adult subjects have been tested according to the following categories: 10 right-hand-dominant males, 10 right-hand-dominant females, 10 left-hand-dominant males, and 10 left-hand-dominant females.

The first dorsal interosseous (FDI) of the hand was tested bilaterally in each subject during constant-force isometric contractions at predetermined force levels. A device called the Muscle Fatigue Monitor (MFM) developed at this laboratory, and recently updated under separate sponsorship, was used to track the median frequency of the surface myoelectric signal recorded from the FDI. The median frequency is considered to be an optimal parameter for objectively and quantitatively measuring changes in the power spectrum of the myoelectric signal which are related to localized muscle fatigue. This data is presently being analyzed with specific reference to measurements of the initial median frequency (the median frequency during the initial 2 sec of a contraction) and the rate-of-change of the median frequency during each sustained muscle contraction. Comparisons of these measures between corresponding contralateral and ipsilateral FDI muscles will be investigated, and the effect of handedness, gender, and force level of contraction will be determined.

Preliminary results suggest that contralateral FDI muscles have different performance characteristics, which are related to hand dominance and possibly to anatomical and/or physiological differences. Handedness should therefore be considered in the design of research studies or treatment programs where fatigability may be a factor, when contralateral limb muscles are compared.

During 1982, clinical applications of the MFM were investigated with further tests on patients affected with muscular dystrophy. Two patients with Duchenne muscular dystrophy tested in our pilot study last year were retested, and these results compared favorably to the patients' clinical course. In addition, other forms of muscular dystrophy were investigated including limb-girdle, myotonic, and Becker dystrophy. Suspected carriers and other family members were also tested. Analysis of these data with the MFM indicates that, in most patients and carriers, the median frequency does not decrease during sustained isometric contractions, particularly at higher force levels.

In order to determine the applicability of this technique for screening and evaluation of patients with muscular dystrophy and other neurological disorders, further tests with the MFM on patients and age-matched controls are planned ■

LIBERTY MUTUAL, NIHR, SWEDEN

THE MUSCLE FATIGUE MONITOR

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Our study, directed at developing a technique for objectively measuring the rate of fatigue in contracting muscles, has led to the design of a device called the Muscle Fatigue Monitor. This device tracks the median frequency of the myoelectric signal detected on the skin above the muscles. (The median frequency divides the power density spectrum into two halves.) Changes in the value of the median frequency appear to be correlated to the progression of localized muscle fatigue.

The present laboratory device is capable of recording and plotting a single channel of information. To perform more complex fatigue experiments, a multiple-channel muscle fatigue device was required. After evaluation of the additional device requirements, a new design was implemented, utilizing digital microprocessor circuitry to process, store and display the median frequency signal. The new device is capable of processing up to four channels of median-frequency information, and an additional four external channels of information such as force,

position, or torque. It also monitors the incoming myoelectric signals for error conditions such as out-of-limit signal or artifacts. The resultant information from each channel can be plotted in a four-color graph, along with text information about the experiment or, if desired, can be stored on cassettes for later evaluation.

The new muscle fatigue monitor is structured for flexibility, allowing rapid change of both hardware and software programming to suit individual experiments. It is also physically small enough to fit inside a briefcase, allowing easy transportation ■

LIBERTY MUTUAL, NIHR, SWEDEN

CLINICAL APPLICATION OF THE MUSCLE FATIGUE MONITOR

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The Muscle Fatigue Monitor has been used in the past 2 years to attempt to assess muscular dysfunction in patients affected with peripheral nerve injury, chondromalacia patellae, and muscular dystrophy. By providing the clinician with a reliable and objective measure of localized muscle fatigue, the Muscle Fatigue Monitor could be useful in the diagnosis, evaluation, and treatment of muscle disorders.

We have investigated further the usefulness of this device in patients with muscular dystrophy. Patients from 4–15 years of age were asked to produce constant force through isometric contractions sustained at various durations and force levels. The myoelectric signals were recorded from the tested muscle group (biceps in the arm and quadriceps in the leg) and analyzed using the Muscle Fatigue Monitor to compute the median frequency of the power density spectrum.

Two Duchenne muscular dystrophy patients tested in our pilot study last year were retested this year: and the results compared favorably to the patient's clinical course. The time rate of change of the median frequency was distinctly abnormal and very similar in all tests. The mother (a carrier) of one Duchenne muscular dystrophy patient was also tested and her findings were surprisingly similar to those of her son. Patients with other forms of muscular dystrophy are also being investigated. Two myotonic dystrophy patients and one limb-girdle dystrophy patient have been tested, as well as some family members ■

NIHR REC

ANTHROPOMETRICAL STUDIES: FUNCTIONAL CAPABILITIES OF AN SCI POPULATION

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Efforts have been directed toward the preliminary tasks that will insure the collection of relevant and meaningful data. A sample target population for initial testing has been defined as those persons who have suffered trauma to the cervical spine resulting in functional quadriparesis and the inability to transfer from a wheelchair. The functional capabilities of persons in the target group are being studied qualitatively by observing these individuals in the activities of daily living, including driving-related activities. A literature review has been conducted to determine the availability of relevant data and the problems and methods of previous investigations of this nature ■

NIHR REC

EVALUATION OF UPPER-EXTREMITY FUNCTION IN CHILDREN WITH CEREBRAL PALSY

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Adaptation of the current data acquisition and handling system used for gait analysis, to evaluate upper-limb activities, has been completed. This included (i) adaptation of computer software for acquiring, analyzing, and plotting data of non-repetitive nature and of longer duration than a gait cycle, and (ii) fabrication and testing of the appropriate chamber and equipment.

An appropriate series of tasks and protocols which can be conducted in a reasonable amount of time were also established. The average time needed for an evaluation was determined as approximately 2-1/2 hours. This consists of 50 minutes for patient orientation to the lab environment and clinical evaluation, 60 minutes to prepare the subject for testing, and 35 minutes for actual testing.

The Gait Analysis Laboratory system was modified to examine the kinematics of upper limb motion (limb-segment motion, shoulder, elbow, and wrist joint angular displacement and velocity changes,

the trajectory of the reach, and the phasing of the grasp).

Data is derived from the films using our Graf Pen sonic digitizer. A total of 20 points are recorded from each frame. Frames at which the various key events of the movement occur (hand lift-off, object touched, object lift-off, object arrives at destination) are marked to determine phases of the movement. The computer is programmed to calculate prescribed information about the quality of the movement, its timing features, its accuracy, its fluidity, and the refinement of the serial ordering of its constituent behavior.

Normal subjects were filmed as they reached to pick up objects from a table in front of them with their right hand. We have found that there is minimal intra- and inter-subject variability in most reaches to a particular object in a particular location. A list of features which describes the dynamics of reaching behavior has been constructed. Features have been identified in both limb-projection and handshaping phases of reaches. Some features vary systematically with the spatial position of the object; for example, the peak velocity of the movements varied with amplitude. Other features are invariant; for example, the percentage of the eventual trajectory traversed when the limb reached peak velocity was invariant with respect to all of the stimulus and effector conditions incorporated in the experiment ■

VA RR&D CENTER HINES

MEASUREMENT OF TRUNK STRENGTH AND FLEXIBILITY IN LOW BACK PATIENTS

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Complaints of low back pain (LBP) are shared by 80 to 90 percent of the adult population. The trunk musculature plays a significant role in maintaining the stability of the spine in different postures. Pathologic changes within the spine often result in abnormal flexibility of involved spinal segments. Such instability of the spine has been considered to be a key mechanical factor in the etiology of LBP. Therefore, quantification of trunk strength and analysis of available trunk flexibility can lend insight to the relationship of these mechanical factors to LBP.

An instrument system is being developed to provide a measure of the isometric trunk strength of a subject in different attempted postures such as bending forward, backward, and sideways directions, twisting, and combinations thereof. This measurement system will also be able to quantify the range of motion of the spine and its distribution within the lumbar and thoracic regions for the different modes described above.

The second phase of the study will use this device to collect data from normal subjects and from patients with low back pain. These data will be used to compare the trunk strength and flexibility in these two populations, in order to identify parameters that can be used to evaluate biomechanically the patients with LBP. It is expected that, upon completion, this study should result in a clinical tool for an objective evaluation of treatment effectiveness ■

VA CONTRACT

RESIDUAL BLADDER VOLUME DETERMINATION FOR SPINAL-CORD-INJURY PATIENTS

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A complete system has been constructed and combined with a full set of computer programs to calculate bladder volume. This system takes scans of the bladder in a known scanning pattern, applies the necessary correction factors to the threshold-detected front and rear bladder wall locations, smooths the data and applies a simple integration algorithm to calculate bladder volume. The preliminary experiments on human subjects indicate that the approach gives accurate measurements of bladder volume.

Design of the system was supported by laboratory experiments performed to validate theoretical calculations of correction factors to be applied to the threshold values used to detect the front and rear bladder walls. Flank steak sections of known thickness immersed in a water tank were used in that work; the sections were formed into planar and circular targets to provide simulated bladder walls at known positions and angles of incidence. Correction factors were developed to account for the effect of pulse width, pulse length, angle of incidence of the ultrasonic pulse on the target, and radius of curvature of the target.

The experimental results validated the need for and accuracy of the correction factors, up to angles of incidence of approximately 55 degrees. (Signal loss at higher incidence angles caused the accuracy to decrease.)

Multiple reflections have been determined not to

be a significant problem if a proper TGC curve is used.

Future work will extend these results in order to improve the accuracy of the system ■

NIHR REC

PREDICTIVE ASSESSMENT IN PRESCRIPTION OF FUNCTIONAL AIDS FOR THE MOTOR DISABLED

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The goal of this project is to develop data and theory on which to base prediction of functional gain from technological intervention. It was proposed that this concept be applied to three handicapping conditions:

1. Disabling tremor of the upper limbs;
2. Loss of vocal communication due to impaired articulatory motor control; and
3. "Equinus" and other spastic gait abnormalities.

With respect to tremor, the present objective is to establish empirically the effect of three hypothetically-useful characteristics of device-control interfaces on the accuracy of displayed movement. The protocol requires that the subjects perform discrete target acquisition and continuous pursuit tracking tasks on a computer-generated video display. They accomplish this by manipulation of either a conventional displacement-sensing joystick or one that rigidly senses isometric force. The control signal can be displayed directly, with low-pass filtering, or with integration which provides control of cursor velocity. Data collected to date shows a significant improvement in signal-to-noise ratio of performance for each of four adult neurology patients disabled by intention tremor, when at least one of the unconventional experimental conditions (force-sensing, filtering, or velocity control) is introduced. While the effects of velocity control and filtering are more nearly consistent across subjects, it appears from examination of several objective performance measures that the best choice of interface characteristics will be etiology-dependent. The data base is being extended at present and, in particular, the difference between the effect of on-line and off-line application of filtering is being determined.

With respect to non-vocal communication, the instrumentation necessary to present touch targets of varying size and position on a large flat panel which generates coordinate signals for finger contact has been completed under other funding (NINCDS). This test panel allows collection of abstract movement data from which a microcomputer program will calculate the predicted words/minute rate for a given user and communication device. Data now being taken is intended to establish how much data must be collected in order to make predictions of mean rate with particular levels of accuracy. For this purpose, subjects are chosen to be present users of devices, and the target sequence is selected by the computer to emphasize those movements most frequently required by the subject's accustomed device. Key issues are the random variance of subjects' movement time and the systematic variation with movement distance, direction, position, and target size. A predictive assessment procedure of clinically acceptable duration will require considerable interpolation among tested values of these movement parameters, and the limits on this data manipulation are being determined.

The spastic gait project, active during the previous REC year, will restart in the Fall of 1983. That work will continue use of the wearable computer-interactive ankle orthosis simulator, which allows generation of energy-absorbing torque profiles across the ankle during gait. The objective will be to generalize upon the single-subject data already collected which shows that the inappropriate ankle extension of equinus can be virtually suppressed by a compliant brace applying a damping-like load during particular portions of the gait cycle. Regression of improvement in gait measures against easily-assessed parameters such as leg length, body weight, walking cadence, and reflex properties will be attempted, in order to determine whether orthosis load parameters may be chosen predictively for each patient. That would permit full-blown gait studies to be eliminated from the clinical assessment of patients for whom a compliant orthosis is being considered ■

SPINAL TRAUMA

HHS, NIGMS GRANT

TRAUMATOLOGY OF THE HEAD AND SPINE

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Computer simulations with a human finite element model should yield the data needed for the prevention of cervical region injuries commonly associated with vehicular accidents. The objectives of this project are the construction of structural finite element computer models of a human and a rhesus monkey head and neck. Experimental data obtained from monkeys will serve to validate the monkey model for simulation purposes. These data, together with in vitro material properties and failure characteristics of the spine of cadavers, will then be used to validate the human finite element model for dynamic simulations ■

VA RR&D CENTER PALO ALTO

STABILIZATION TRANSPORT SYSTEM (STS) — A TREATMENT-COMPATIBLE TRANSPORT SYSTEM FOR SPINAL INJURY PATIENTS

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Need — An improved spineboard with traction is needed to reduce the risk of trauma to cervical spine injury patients during transportation and treatment. It should be compatible with transport equipment, computed tomography (CT) scanners, standard radiographic equipment, and hyperbaric oxygen (HBO) chambers.

Approach — Our approach has been to develop working prototypes of the Stabilization Transport System (STS), have them field-tested at local spinal injury centers, and upgrade the functional specifications for subsequent prototypes.

Status — Two prototypes of the STS have been developed to date. The first prototype, of X-ray radiolucent mahogany, laminate construction, incorporated constant-tension-spring traction to minimize traction force disturbance during transport. The second prototype, a composite of fiberglass over a styrofoam core, was built to determine the applicability of a composite construction for ease of manufacturing. This second prototype included an alternative constant-tension-spring traction system configuration. Both prototypes incorporated posture stabilization (padded structural restraints and belts), and padding to minimize pressure-sore development. The fiberglass composite second prototype exhibited diffraction patterns in CT scan tests. However, the fiberglass composite was considered a mock-up for a carbon fiber composite which is expected to be radiolucent.

Three of the first STS prototypes were built. Two of these have been in use and testing at Santa Clara Valley Medical Center in San Jose, California, for more than 2 years. The third has been readied for field testing at R. K. Davies Hospital in San Francisco. The second STS prototype requires minor upgrading before it will be ready for specific field testing at either of these spinal-cord-injury centers ■

VA RR&D CENTER HINES

MATHEMATICAL MODELING OF THE HUMAN SPINE: IMPLICATIONS FOR THE SURGICAL CORRECTION OF SPINAL DEFORMITIES

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Structural deformities of the spine such as scoliosis, kyphosis, and spondylolisthesis are treated surgically when conservative treatment using braces or orthoses fails to stabilize the trunk. A typical surgical

treatment modality involves correction of the spinal curve by instrumentation such as Harrington distraction or compression rods, segmental wiring, or other techniques. Each instrumentation system exerts certain forces and moments on the spine so as to reduce its curvature.

The purpose of this study is to develop a computer model to help the clinician select the most appropriate instrumentation system for a given patient. To accomplish this, the model must closely predict the individual mechanical spinal response for each patient. Thus, in the past, general models which were based solely upon in-vitro experimental data were deemed unacceptable. Alternatively, a computer model has been developed that utilizes an optimization procedure to identify the mechanical properties of an individual human spine, such that the model's 3-dimensional displacement response matches that of an in-vivo spine. Data required for this model are easily obtainable for each patient from roentgenographic recordings of their spinal response to simple traction loadings. This model utilizes 3-dimensional finite element beams to simulate each motion segment. The optimization is performed interactively at a computer terminal and incorporates a graphics display to help the analyst in the identification process. With the mechanical properties thus established, a computer simulation can be performed to examine the efficacy of various corrective procedures and instrumentations ■

VA RR&D CENTER HINES

MATHEMATICAL MODELING OF THE HUMAN SPINE: IMPLICATIONS FOR THE ORTHOTIC MANAGEMENT OF SPINAL DEFORMITIES

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Mild to moderate curvatures of the spine are most often treated conservatively using an orthosis such as the Milwaukee brace or the Wilmington jacket. The mechanics of curve progression is of considerable interest to the clinician, due to its implications to patient selection for orthotic treatment as well as choice of an orthosis.

The purpose of this study is to investigate the stability of a scoliotic curve with and without bracing as a function of the degree of initial curvature (at the time of orthotic intervention) and of the amount of stabilizing transverse load exerted by an orthosis on the spinal curve. Mathematical modeling of the spine-orthosis system involves inelastic buckling analysis of an initially curved and transversely loaded flexible column. The model can simulate the interaction of different types of orthoses with the spinal curve.

This analysis suggests a biomechanical explanation as to why larger curves are more progressive than smaller curves, and why bracing is effective in only small and moderate degrees of scoliosis. This analysis should aid in patient selection and prediction of results ■

VA RR&D CENTER HINES

PASSIVE ELECTRICAL PROPERTIES OF THE SPINAL CORD

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The electrical impedance of the spinal cord can be modeled as a resistor and capacitor in parallel. Assuming that we could effectively eliminate electrode polarization, we tested this model by connecting a high-impedance resistor in series with the cord, using a high frequency input signal and comparing the voltage change and phase shift in relation to the input signal.

Wistar rats weighing approximately 300 gm were anesthetized by an intraperitoneal injection of chloral hydrate. Laminectomies were performed exposing the lumbar-thoracic region of the spinal cord. The rats were suspended in a spinal stabilization frame to eliminate respiratory motion artifact.

Either silver or chlorided-silver electrodes fabricated in our laboratory were used. The electrodes were exposed 0.5 mm from the tip with a tip diameter of 5 μm and a shank diamter of 2 mm away of 200 μm. They were inserted into the cord at a depth of 1 mm and held 2 cm apart, using micromanipulators. A resistor in the range of 100 kilohms was connected in series, and a current signal at a frequency of 100 kilohertz and a voltage below stimulation threshold was applied. The input signal and the signal off the cord were measured and compared using a Dynatrac 393 Lock-in Amplifier.

The measurements obtained from the cord produced resistivity measurements. The mean was determined to be 147.51 ohm-cm + 28.27 ohm-cm at probability of 0.05. This result falls within the range which Ranck determined for cats (Expt. Neurol., 11:451-63, 1965). The capacitive reactance unfortunately was unobtainable with our present equipment. The input impedance of Dyntrac is shunted by a 40 picofarad capacitor that gives the machine a capaci-

tance sensitivity limit of 1 picofarad. Since our measurements showed only this 40 picofarad phase shift, we surmised that the capacitance of the cord was less than 1 picofarad.

In conclusion, at 100 kilohertz the longitudinal impedance of the spinal cord in Wistar rats consists mainly of a resistive component. The resistivity was found to be in a range of 135 to 172 ohm-cm. The capacitive component of the cord was essentially nonexistent, with an upper limit of 1 picofarad. In view of the reported resistance of pia mater and CSF, 50–100 ohm-cm² and 64 ohm-cm respectively (Med. & Biol. Engng. 5:271–93, 1967), it is suggested that the electrodes should be placed below the pia mater in order for minute currents to be effective ■

VA RR&D CENTER HINES

POSSIBLE STABILIZING EFFECTS OF NGF ON SPINAL FIBERS

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Much of the present research aimed at assessing the potential for recovery following spinal injury is concerned with the evaluation and stimulation of regenerative events in injured CNS neurons. Usually, the effect of a pharmacological intervention on regeneration is evaluated in terms of neurite elongation or return of electrophysiological function. In many instances, in situ anatomical studies of axonal regrowth and reorganization of injured tissues are used as an index of the effects of substance being tested for its effects on regeneration. Similarly, studies probing the effects of modulators of regeneration on recovery of function rely on whole-animal functional recovery as indexed by neurological or behavioral criteria. One problem with these assessments is that it is difficult to distinguish between primary effects of CNS tissues under study, and secondary effects acting perhaps through other non-CNS tissues.

As an example, there are reports that NGF (nerve growth factor) may act on CNS targets. Most interestingly, it has been suggested that NGF may accelerate regenerative events in CNS. To test this hypothesis, rats were injured by the modified Allen technique, and were treated with NGF in order to assess if NGF had beneficial effects. 1251-NGF was used to determine if the NGF was acting directly on central structures. Our results suggested that the beneficial effects on injured spinal fibers were secondary effects due to the action of NGF on peripheral dorsal root ganglia ■

VAMC WEST HAVEN

MECHANISM OF CERVICAL SPINE INJURIES

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The specific goals of this project are to determine:

1. The forces needed to produce injuries in vitro in a three vertebrae segment of human cervical spine;
2. The displacements and deformations of the vertebrae and spinal canal during injury;
3. The stiffness of each spine specimen before and after injury; and
4. The roentgenographic (CT-scan, etc.) changes due to the injury.

Progress to Date — Several cervical spines have been harvested and preserved at – 20 degrees centigrade. The injury production apparatus has been built. Two canine spines have been fractured in the apparatus. Both spines were subjected to pure compression. Only the compression force was monitored during the injury; at this time no motion data was recorded. CT-scans and X-rays were taken of each segment before and after injury. A segment-holding jig insured accurate positioning.

The results from the tests indicate that the apparatus works well. It is capable of fracturing vertebra at high speeds (over one m/s). Future work will include the refinement of the injury production apparatus, implementation of data sampling by computer, and the collection of motion data ■

VAMC PALO ALTO

EVALUATION OF FIXATION METHODS FOR THE CERVICAL SPINE

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Little quantitative data exists as to the effectiveness of fixation devices used in the treatment of spinal injuries. Until the quantitative data is obtained, the physician will lack substantive information for the selection of the best treatment.

The goals of this study are: first, to collect data on

methods of internal stabilization of the cervical spine. This data will assist the physician in selecting the appropriate treatment. The devices that will be evaluated are interspinous wiring, interspinous wiring with transverse pins, segmental facet wiring, and an experimental device — a "U-rod".* The second goal is to pursue an improved system of internal fixation which will be stronger and more durable than current methods. That would reduce the risk of failure, and the need for external stabilization. In this progress report, work towards the first goal will be discussed, since work on the "design phase" is just beginning.

To record spinal motion, a specially designed motion transducer is mounted between C5 and C6 (1). The transducer measures all six degrees of freedom continuously while the spine is in motion. The motion is resolved into 3 rotations and 3 translations of the C6 vertebrae relative to the C5 vertebrae. The rotations are accurate to about a degree. Translations are sensitive to the transducer installation, and thus allow comparison between devices on a given spine, but not between different spines.

Protocol — The intact spine is loaded in each direction, with vertebral motion being recorded. The spine is then disrupted between C5 and C6, and instrumented with a stabilization device. (The disruption consists of cutting through all structures except the anterior longitudinal ligament. This corresponds to a rather severe injury, and is thus a demanding test for fixation devices.)

Preliminary Results — Sample data show that, as expected, the dominant rotation is axial, with coupling to lateral and A/P motion being apparent. The limits of motion are considerably greater than in the intact spine, with interspinous wiring permitting the greatest motion. Stiffness is similar between the U-rod and the intact spine, with interspinous wiring being slightly more compliant.

Because this data is from only one spine, and because the protocol is still being refined, these data samples cannot stand alone. However, they illustrate that the apparatus can provide very precise and complete data on the motion of the spine. In addition to allowing a comparison of stabilization devices, this data promises to enhance our overall understanding of the motion of the spine ■

*The U-rod is simply a 5/16 inch stainless steel rod which has been bent so that it runs up one side of the spinous processes, across to the other side, and down the other side of the spinous processes. It is also contoured to the curvature of the spine. It is wired in segmentally, much like Luque Rods, from C4 through C6.

HHS, NIGMS GRANT

HEAD / NECK / UPPER TORSO RESPONSE TO DYNAMIC LOADING

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The purpose of this project is the construction and instrumentation of a 3-D model of the head, neck, and upper torso containing artificial structural elements of the major organs and anatomical features such as: major vessels, ribs, major muscles, heart, lungs and spinal column. The model will be used to study impact dynamics and to formulate a mathematical model to evaluate possible protective devices for the human body ■

MUSCULOSKELETAL REHABILITATION

NIHR REC

MULTICENTER TRIAL OF THE L.E.S.S. TECHNIQUE FOR SCOLIOSIS TREATMENT

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The purpose of this project was to determine whether the Lateral Electrical Surface Stimulation (L.E.S.S.) technique developed at Rancho Los Amigos Rehabilitation Engineering Center would be as effective in the hands of other clinicians as it had been for the originating investigators.

Patients studied were juvenile or adolescent idiopathic scoliotics within current selection guidelines for the Milwaukee brace or other conventional orthoses. Within that population, a subgroup was selected for separate analyses because of the high probability of continued curve progression.

The major curve (the deformity component defining treatment) had to have a magnitude from 20 deg to 45 deg. Major curve magnitudes less than 30 deg had to show clear evidence that the deformity was actively progressing at the time of observation. For curve magnitudes of 20 deg to 24 deg, the curve must have progressed at least 10 deg in the immediately preceeding 6 months and be documented on at least two X-ray films. For major curve magnitudes of 25 deg to 29 deg, the curve must have progressed at least 5 deg in the last 6 months. With these immature

patients, curves of 30 deg or more were assumed to be highly progressive.

The patient population consisted of 548 patients from 54 clinics in North America and Western Europe. The curvatures were subdivided into a normal risk, 20–29 degree group, and a high risk, 30–45 degree group. Nineteen percent (19%) of the patients belonged to the selected "protocol" group. Eighty-nine percent (89%) of the population had been treated less than 2 years.

To assess the immediate effects of beginning treatment during active deformity progression, the curvature progression rate calculated over an interval immediately preceeding treatment was compared with the interval immediately after initiating treatment.

Treatment was terminated prior to skeletal maturity in 24 percent of the patients. No cause was stated in 14 percent, while the remaining 10 percent was distributed between noncompliance (50%), skin irritation (20%), intolerance (7%), and other (23%). Of all dropouts, progression occurred in 63 percent (15 percent of total population) and no change in 37 percent.

Despite a relatively high incidence of minor adverse effects, we could only identify 15 patients of the 548 (less than 3 percent) who appeared to be forced to discontinue treatment because of the adverse effects. The vast majority of problems were reversible and manageable. By far, the most common adverse effect was skin irritation.

These data indicate that the external stimulation technique originated at Rancho Los Amigos Rehabilitation Engineering Center stabilizes actively progressing juvenile or adolescent scoliosis, at least until spinal maturity ■

VA RR&D CENTER HINES

BIOMECHANICAL STUDY OF TREATMENT MODALITIES FOR LUMBAR DISC DISEASE

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Lumbar disc disease is a common problem facing the orthopedic surgeon and neurosurgeon. Patients suffering from this condition with neurologic deficit, and unresponsive to conservative therapy, have routinely been treated surgically by laminectomy and discectomy. Recently, however, there has been an increasing interest in a more "conservative" treatment: dissolution of disc material by chymopapain injection. After extension animal studies and clinical trials, such "chemonucleolysis" has been approved in the U.S. A physician treating lumbar disc protrusion must now choose between two effective treatment options — laminectomy or discectomy, or chymopapain injection.

The purpose of this investigation is to compare the biomechanics of these two treatment methods in the laboratory, utilizing cadaver specimens of the human spine. Specifically, the study is aimed at examining the changes in the loadbearing behavior of the disc and the facet joints immediately following either of these treatment methods. It is hoped that a better understanding of alterations in the biomechanics of the lumbar spinal segments will significantly aid the physician in selecting a method of treatment ideal for a patient ■

NIHR REC

AUGMENTED-FEEDBACK SCOLIOSIS ORTHOSIS

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The Augmented Feedback Scoliosis Orthosis (A.F.S.O.) uses tactile feedback to motivate patients with idiopathic scoliosis to perform a specific spinal exercise while wearing the orthosis. (It also provides passive correction when the person is not doing the exercise.)

The conventional thermoplastic T.L.S.O. (thoracic-lumbar-sacral-orthosis) relies on purely passive correction. The conventional Milwaukee orthosis is often prescribed in conjunction with an exercise program to encourage the patient to actively decrease his/her scoliotic curve for brief periods each day. The Feedback Orthosis combines the features of passive correction with a "built-in" electronically monitored exercise program. When the person performs the "lateral shift" spinal exercise correctly, a timer inside the orthosis is activated which unobtrusively reminds them to do the exercise again in about 40 minutes. The newer A.F.S.O.'s count the number of shifts done by the patient up to a period of 3 months.

Of the 16 patients in the current series, 11 have been followed 12 months or longer. Of these 11, four major curves have decreased five degrees or more, four were unchanged, and three have progressed more than five degrees. Five patients have been followed for less than 12 months. One patient was treated surgically because of progression, and three have been eliminated from the study because of noncompliant follow-up. These preliminary results

are no worse than anticipated with conventional Milwaukee bracing or T.L.S.O.'s.

The current orthoses are prototypes that are under clinical evaluation. The device has not been proved clinically effective and is therefore not yet ready for release as a treatment mechanism ■

VAMC DALLAS

OBJECTIVE ASSESSMENT OF HUMAN SPINE FUNCTION

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The University of Texas Health Science Center at Dallas, Orthopaedic Surgery, and The University of Texas at Arlington, Biomedical Engineering

The purpose of this project is to develop an objective assessment of patients with low back pain through the application of power spectrum density techniques to myoelectric signals obtained in the course of endurance testing. For many reasons (e.g., deep muscles, lack of right versus left comparisons, multiple small segments), it is difficult to obtain quantitative information on gross strength and fatigue or endurance of lumbar spine muscles. Myoelectric signal techniques, although developed primarily to assess muscle function of the upper and lower limbs, may lead to an improved understanding of human lumbar spine function and to a reduction of economic and social costs of low back pain.

Results of our initial studies were reported at the Orthopedic Research Society meeting in Anaheim, California, in the Spring, 1983. Since then we have designed and are completing construction of an isometric trunk-strength device. It utilizes a heavy frame that places the patient in the standing position. The patient is stabilized at the feet, knees, pelvis and chest, with the knees bent slightly to decrease the effect of hamstring tightness. We designed the device to be compatible with a prototype frame which may soon be available commercially for clinical testing and training.

Much work remains to be done before myoelectric signal power spectrum frequency analysis comes into clinical use. The technique offers an opportunity to demonstrate right/left imbalance in trunk muscle function, to give endurance information complementary to gross strength tests, to demonstrate evidence of progress in rehabilitation programs, and possibly to identify substandard effort ■

LIBERTY MUTUAL, NIHR, SWEDEN

BIOFEEDBACK DEVICE

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As a result of a collaborative effort by engineers in our laboratory, physical therapists in Children's Hospital Medical Center in Boston, and patients, a myofeedback device called "Myobeeper" was designed and constructed. This device provides an audible tone and light display which are proportionally indicative of the level of a muscle contraction. It accomplishes this task by processing the myoelectric signal detected from the surface of the skin.

Three generations of this device were field-tested in busy medical centers to determine its acceptance and usefulness to clinicians in the daily operation of their environments. Myobeeper was widely accepted by clinicians as a compact, portable, and lightweight device that was convenient and easy to use. Its usefulness as a myofeedback instrument was determined by the variety of its applications to treatment needs and by its ability to obtain immediate, reliable, and objective data that could be documented. The salient feature of the device which rendered it so useful in clinical environments was the dry electrode used to detect the myoelectric signals. This electrode is capable of detecting the myoelectric signal within 2 seconds after coming into direct contact with the skin. This device has attracted the attention of a manufacturer who is actively pursuing the possibility of producing it ■

VA RR&D CENTER HINES

THE DEVELOPMENT OF AN INSTRUMENTED ANIMAL MODEL TO STUDY THE NEURAL MECHANISMS UNDERLYING BLADDER DYSFUNCTION AFTER SPINAL TRAUMA

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If a patient survives the initial trauma of spinal injury, more than likely he will have a problem regulating his bladder function. Such bladder dysfunction can be life-threatening, since it can lead to kidney infection and damage. Most of the neurological research into the paralysis and/or spasticity of muscle following spinal trauma has focused on skeletal muscles. Much less has been aimed at understanding bladder dysfunction following such trauma. Moreover, there remains a need to develop an animal model of such dysfunction where the animal is awake and able to interact (at least above the lesioned area) with his environment, so that the animal's bladder function can be studied over the long term. With such a model, the effects of various new pharmacological and surgical interventions or electrostimulation techniques could be assessed.

We have adapted techniques developed for cardiovascular research to produce such a model, in which bladder performance can be continually evaluated through a knowledge of the relationship between bladder volume and pressure. Such a relationship, clinically called a cystometrogram, yields information about the functional state of the bladder. Under surgical anesthesia, we implant into the bladder a state-of-the-art miniature (4 mm diam) transducer to measure pressure. At selected sites on the bladder surface, pairs of small ultrasonic crystals are placed. Their distance apart can be measured and used to determine bladder volume. We also can install leads to measure detrusor and pelvic floor muscle electrical activity (EMG). The leads for these devices are then tunnelled under the skin to exit from the back of the animal's neck, and are protected in a vest worn by the animal. So far, we have instrumented siz monkeys. The bladder function of these animals has been observed before and up to 1 month after instrumentation. The model has worked well. It now gives us a tool to monitor bladder function and dysfunction before and after spinal trauma ■

NIH MUSCULOSKELETAL

EXERCISE-TRAINING: EFFECTS ON MUSCLE FATIGUE

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The primary objective in this project is to continue experiments designed to elucidate the effects of use (exercise-training and chronic electrical stimulation) on fast and slow skeletal muscle, and determine to what extent and by what mechanism exercise training protects against the development of fatigue. The long-term objective is to understand the molecular mechanisms controlling muscle function and how they are altered by exercise-training and by fatigue, so that this knowledge can be used in the prevention of fatigue and disease and in rehabilitative medicine. The effect of endurance training and high-intensity, short-duration exercise training on muscle function and the etiology of muscle fatigue will be studied in the rat.

The physiological studies will include an in situ evaluation of the contractile properties of the slow-twitch soleus and fast-twitch extensor digitorum longus (EDL), and in vitro studies of these muscles plus the fast-twitch superficial region of the vastus lateralis (SVL) at rest and during acute contractile activity. The intracellular H^+ ion concentration will be directly measured using pH-sensitive glass microelectrodes and pH changes during work will be determined. The pH changes will be correlated to alterations in substrate levels and contractile properties, to assess the role of H^+ in muscle fatigue. The skinned fiber preparation will be used to determine how exercise training and fatigue affect sarcoplasmic reticulum (SR) and myofibrillar function. The contribution of myofibrillar and SR ATPases to the total activity will be determined and these activities correlated to maximal shortening velocity and force transients, respectively. The sarcoplasmic reticulum (SR) will be studied to determine how exercise training and muscle fatigue affect the kinetic properties, phosphorylation, and gel electrophoretic patterns of this membrane system.

The effect of chronic electrical stimulation on the contractile properties of rat fast and slow skeletal muscle will be determined, using both the whole muscle and skinned-fiber preparation. The SR and myosin proteins will be analyzed and alterations correlated to specific changes in mechanical properties. These experiments are designed to test the hypothesis that the SR controls the intensity and duration of the active state, while the maximal speed of unloaded shortening is dependent on the myosin ATPase activity ■

NIH MUSCULOSKELETAL

ADAPTION OF MUSCLE TO HIGH-RESISTANCE EXERCISE

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The objectives of the research are to further define the process whereby the neuromuscular system adapts to high-resistance (weightlifting) exercise, and to investigate the mechanisms that control exercise-induced muscle growth.

Adult cats are operantly conditioned to flex their right wrists against increasing resistance to receive a food reward. This procedure has the advantage of inducing significant hypertrophy in the muscles of the right limb, while the muscles of the left limb can be used for comparative studies. Increases in both muscle fiber cross-sectional area (hypertrophy), and number (hyperplasia), are thought to occur in response to weightlifting exercise, and this study will seek definitive experimental evidence as to the contribution of each of these mechanisms to exercise-induced muscle growth.

In the study, the ultrastructural and histochemical features of exercised muscle fibers that are undergoing necrosis and regeneration will be characterized. It is anticipated that this project will provide insight into the mechanisms controlling muscle fiber necrosis and elucidate the stem cell population involved in regeneration. This study will provide a unique opportunity to investigate muscle fiber turnover induced by physiological stress. Also, quantitative ultrastructural measurements of muscle fibers will be made to provide insight into the reorganization that occurs in response to exercise. The physiological, histochemical, and morphological characteristics of motor units will be determined in the wrist flexor muscles. Adaptive changes in the motor unit properties in response to exercise will be investigated.

These studies will be the first extensive survey of the mechanical properties of forelimb motor units. In addition, no studies have assessed exercise-induced changes in the motor unit properties. These studies are made all the more important by the observations of exercise-induced muscle fiber necrosis and regeneration and the possibility of hyperplasia, to determine if these processes are independent of nervous system (motor) control.

This study will continue to elucidate the dramatic structural and functional alterations that occur in the neuromuscular system in response to prolonged weightlifting exercise. An understanding of how muscle adapts to physiological stress should provide insight into the pathophysiology of muscle ■

LIBERTY MUTUAL, NIHR, SWEDEN

MUSCULAR FATIGUE AND THE MYOELECTRIC SIGNAL

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Previous reports have indicated that the myoelectric signal can be reliably used as an objective measure of localized muscular fatigue in humans. A major effort of this project is to identify the various parameters of the myoelectric signal which will optimize the detection and assessment of localized muscular fatigue. It is suspected that a change in the muscle fiber conduction velocity may be a significant factor during fatigue which may alter the characteristics of the myoelectric signal. Therefore, the muscle conduction velocity will be directly measured during fatigue with surface recording techniques and compared with the various derived parameters representing certain characteristic changes in the myoelectric signal.

Parameters which track the shift in the power density spectrum of the myoelectric signal, and parameters of the myoelectric signal, such as zero-crossing and RMS values, will be compared and analyzed to achieve the most accurate, precise, and reliable representation of either the metabolic state of the muscle or a quantitative indication of its fatigue properties. Once the optimal parameter or parameters have been selected, this technique will be valuable in a clinical environment due to its completely noninvasive approach.

We have started experiments to monitor the behavior of the myoelectric signal during both static and dynamic isometric contractions. The dynamic contractions will provide a greater understanding of the interactions between blood flow and the fatigue properties of muscle. These experiments could predict the performance of muscles during strenuous activity, as required in some work environments or during exercise activities ■

NIH MUSCULOSKELETAL

CONTROL OF MUSCLE PROTEIN METABOLISM DURING EXERCISE

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The broad objective of this research is to study the changes that occur in protein metabolism as a result of exercise, and to establish the underlying biochemical mechanisms which bring about these changes. In research already completed, it has been clearly established that an acute bout of exercise (either running or swimming) causes a decrease in the rate of muscle protein synthesis and increased rates of protein degradation in muscle and liver. Preliminary evidence from the lab, and reports from other investigators, suggest that an acute exercise bout also increases the rate of amino acid oxidation.

During the next granting period it is proposed to further study the effect of an acute exercise bout on protein synthesis, protein degradation, and amino acid oxidation. To determine mechanisms involved in the decrease in protein synthesis in muscle, the effect of exercise on the various components of protein synthesis will be determined: charging of t-RNA, initiation of peptide synthesis, and peptide elongation. An experiment will be conducted to investigate whether an acute bout of exercise increases alanine production by the isolated epitrochlearis muscle.

In addition, an investigation of the biochemical regulation on leucine oxidation in muscle during exercise will be continued ■

NIH MUSCULOSKELETAL

SKELETAL MUSCLE REHABILITATION FROM LIMB IMMOBILIZATION

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Skeletal muscle will be from limbs that are rehabilitating from atrophy caused by a prior 7-day period of hind-limb immobilization in rats. The specific aims of the research plan are to:

1. Determine the synthesis rates of actin and cytochrome c in skeletal muscles at the sixth hour, second day, and fourth day of recovery from the prior 7-day immobilization. Synthesis rates are estimated in vivo by the constant infusion of ^{3}H-tyrosine, measurement of the specific radioactivity of either purified actin or purified cytochrome c, measurement of the specific radioactivity of tyrosyl-tRNA, and calculation of the estimated rate of fractional synthesis per day.

2. Determine the role of anabolic steroids and of various exercises (treadmill running, weight lifting, and electrical stimulation) in addition to "normal" cage activity on the synthesis rates of actin and cytochrome c in skeletal muscles on the second day of recovery from the prior 7-day period of hind-limb immobilization.

3. Determine the threshold of exercise duration needed to increase the synthesis rate of actin and cytochrome c in skeletal muscle on the second day of recovery from a prior 7-day period of hind-limb immobilization.

4. Determine the sensitivity to increasing exercise duration of the amount of increase of actin or cytochrome c synthesis rates.

5. Determine the content of actin mRNA and of cytochrome c mRNA in skeletal muscles at the sixth hour, second day, and fourth day of recovery from a prior 7-day period of hind-limb immobilization. The content of actin mRNA or cytochrome c mRNA will be semiquantitated by dot hybridization with cDNA for actin mRNA from rat skeletal muscle and a genomic clone of rat liver cytochrome c, respectively.

6. Determine the content of actin mRNA and cytochrome c mRNA in skeletal muscles in the 3rd and 24th hours after an exercise bout when exercise is performed on the second day of recovery from the prior 7-day period of hind-limb immobilization ■

INFORMATION

NIHR REC

DEVELOPMENT OF WORKSHOPS AND RELATED INSTRUCTIONAL MEDIA FOR NATIONWIDE DISSEMINATION OF TECHNOLOGICAL INFORMATION

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Introduction — This project proposed development of two workshops and related instructional materials to disseminate information to disabled consumers and allied health professionals which would assist them in solving their own or their client's problems in specific areas. Selection of the topic areas for the workshop and media was based on a community survey and numerous requests for information. The

workshops were conducted locally, and the materials were developed for national distribution.

Methodology — The technique used to identify workshop topics of concern to disabled consumers and allied health professionals was a community-based survey. A questionnaire which utilized forced choice and open-ended questions was sent to a wide variety of consumer groups and service-providing agencies during October, 1981.

Progress — Two topics were selected for workshop and media development, based on the results of the community survey and on personal contact with consumers with disabilities and allied health professionals. The selected topics — Home Organization and Home Access — were developed and presented two times each for a total of four workshops. The participants in these workshops included consumers with physical disabilities, their family members, and allied health professionals. The workshops were conducted as a preliminary step to development of audio-visual materials which could be distributed nationwide. In this way, information on these topics of concern to many persons with physical disabilities would have impact on far more individuals than if the information was limited to one geographic area. Conducting the workshops allowed incorporation of consumer comments and suggestions into the development of audio visual materials ■

NIHR REC

INFORMATION DISSEMINATION AND SERVICE DELIVERY

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Communication with the professional and user communities continued through the participating of the UM REC staff at RESNA, at the Association of Driver Educators for the Disabled (ADED), and other meetings.

Publication of the UM RECorder continues on a schedule consistent with UM REC needs. The UM RECorder and other UM REC publications are transmitted to the National Rehabilitation Information Center (NARIC) in Washington and to the National Clearinghouse on Rehabilitation Materials in Stillwater, Oklahoma for permanent storage and distribution ■

NIHR REC

EDUCATION AND TRAINING, RESOURCE INFORMATION

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Community Education — A workshop series entitled, "Special Problems in Rehabilitation Engineering," was conducted in the spring of 1982. It included one-day and two-day offerings, such as: Seating Needs for Children; Adult Seating and Tissue Trauma Management; and Language, Computers and Communication.

The Rehabilitation Engineering Clinical Internship was started at this Rehabilitation Engineering Center in 1979. It is designed to provide multidisciplinary clinical training to an individual with a background in engineering interested in applying his/her expertise to the rehabilitation needs of the disabled. The program accepts one applicant per year (November-October) and focuses on patient contact across a variety of clinical services and settings.

Information dissemination activities include the development of an independent technology resource center (Tools for Living in the Community); a publications office; support of the Abledata Information Service; and development of resource guides and bibliographies, and data sheets ■

Sensory Aids R&D

In this section, under the broad heading of Sensory Aids R&D, reports in the following general areas will be found: **Blindness and Visual Impairment** (including **Orientation and Mobility, Reading Systems for the Blind,** and **Low Vision**); **Systems for the Hearing Impaired; Speech Technology; Speech Impairment/Aphasia.**

BLINDNESS AND VISUAL IMPAIRMENT

VA RR&D CENTER HINES

EFFECTIVENESS OF A BLIND REHABILITATION PROGRAM

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In a study designed to assess the effectiveness of the Blind Rehabilitation Center, it was necessary to develop instruments which would measure "quality of life."

The model required that a patient's life state be measured prior to entry into the rehabilitation program; shortly after completing the rehabilitation program, and again 6 to 9 months later. One hundred and ninety patients have completed initial interviews; 110 patients have completed second interviews; and 63 patients have completed third interviews. The data collection process is continuing and further efforts are of three sorts: (i) continued analysis of the measuring instruments validity; (ii) preparation of the programs and data for future analysis and (iii) integration of the data into a larger data base management system.

All of our measuring and survey instruments have been constructed. Most have been thoroughly tested, analyzed, and reported in the literature. The attitude-toward-blindness scale has been evaluated and compared to existing measures. The usefulness of the measure in a rehabilitation program is discussed in another paper. The method of scaling used in developing the measure is now being compared with factor analytic techniques.

Data have been collected in order to measure change-in-life state over time. Such measurement requires unidimensional scaling, which in turn makes necessary the development of new and innovative programs for analyses by use of a computer.

Two information systems have been constructed for the blind rehabilitation evaluation project. A large amount of data is collected from each patient in multiple interviews. There is a demographic file, a medical history and physical examination, an ophthalmologic examination, and five separate survey instruments each of which is administered three times. The information system to manage the flow of work and data is an easily mastered user-friendly system which can be adapted to many types of project management. The patient information resides in a data base management system which is an industry standard DBMS with full security protection and privacy locks. It has the capacity to be used by many different programs and can easily be adapted to other research projects ■

VAMC ATLANTA

MUSICAL LANGUAGE COMPUTER APPLICATIONS

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This system provides the blind user a lower-cost means of accessing information from digital sources.

Progress — This system originated as a graduate feasibility study. It has now been implemented into the "SONA Tune-Maker" (SONA is an orientation & navigation system with environmental control applications, reported elsewhere in this issue). Data-gathering from users in the field continues, and persons interested in using the language are encouraged to contact us. A survey determining the needs of users is presently being conducted in order to assist the development of software meeting user needs in computer applications where muscial language can be an alternative to voice output.

Implementation of the first SONA devices with musical-language output has begun. This system will be tested as reported under SONA.

Future plans — Plans are to continue data acquisition from volunteer users and implement the SONA Tune-Maker into "real-world" use. Plans are presently to assist manufacturers in implementing this system into new equipment, including talking terminals. This work is expected to continue at the Atlanta Veterans Administration Medical Center ■

VAMC ATLANTA

SONIC ORIENTATION AND NAVIGATIONAL AID

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The SONA/ECS is a digital radio transmitter-receiver system that has applications for the visually impaired as an orientation aid, and for the manually impaired as a Decentralized ECS (Environmental Control System).

Progress — The first SONA/ECS system has had a limited evaluation by three quadriplegics who have utilized the system in their homes or on the job for periods of 3 months to 1 year. Preliminary results indicate that the system is very successful at providing reliable decentralized control at a relatively low cost.

One unit has been constructed and tested that provides automatic remote control over van doors and van wheelchair lifts. This system allows the quadriplegic to open the van doors from as much as 80 feet away from the van using a transmitter carried on the wheelchair.

The system has been commercialized by Amber Enterprises, Inc., Atlanta, Georgia. A 60-channel system is being constructed by the company for installation in a home in Florida. Amber has developed the system to control dimmer functions for dimming lighting, motor speed control for ventilation, and volume control for music systems. The company will make units available for testing and evaluation on a purchase order basis.

The SONA (Sonic Orientation and Navigational Aid) for the visually impaired traveler has been produced in sufficient numbers to allow the first field testing to be scheduled at the Atlanta Veterans Administration Medical Center. Thirty-five units have been produced. Initial field-testing awaits installation of the units in the hospital where they will be used to give visually impaired clients easier access to important facilities within the hospital. The units are equipped with the new "tune-maker" musical language board developed since the previous progress report. The tune-maker has been redesigned to be less labor-intensive in production and to have a slightly lower unit cost. This unit is expected to be available from Amber Enterprises, Inc. early in 1984.

Future plans — The Atlanta Veterans Administration Medical Center intends to continue development and evaluation of this system in both of its aspects.

This research will center in two main areas: broadening the present applications of the ECS features, and evaluating the utility of SONA to the visually impaired traveler.

Technical development will also emphasize production engineering of the products, including the application of human-factors data gathered during testing ■

ORIENTATION AND MOBILITY

VA RR&D CENTER HINES

THE EFFECTS OF PREVIEW DISTANCE ON THE MOBILITY OF THE BLIND PEDESTRIAN

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The optimal distance at which blind pedestrians should receive information regarding their upcoming environment is an important variable for the design of mobility aids. Previous research in this area has not provided a definitive distance or range of distances for the necessary foreknowledge or preview of the environment.

We hypothesize that a decline in performance indicates an insufficient amount of preview for the blind pedestrian. Insufficient preview does not allow sufficient time to respond appropriately to upcoming environmental features, and it also disrupts the pedestrian's processing of other, more global, mobility and orientation information such as route knowledge. Thus, this project assesses a range of these preview distances to determine at what distances both the overall mobility, and a set of specific parameters of gait-related mobility, deteriorate.

This study should yield significant insight into optimal preview distances. Then, future mobility aids can be designed to be more informative and compatible with the user, and less disruptive of the basic psychological processes that underline mobility ■

VA RR&D CENTER HINES

MEASURING THE MOBILITY OF BLIND TRAVELERS

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To perform a valid evaluation of a training program in blind mobility, the means for measuring the effect of that program on the blind traveler must be available. Previously, two quite different approaches have been taken in assessing the blind person's mobility performance: (i) measuring, either qualitatively or quantitatively, the travel skills of the blind person or (ii) ascertaining the amount and type of travel in which the blind person is reported to have engaged. Earlier attempts at measuring both of these have been less than optimal. Moreover, the two types of measures have never been compared in relation to each other. It is now possible to determine the effect of travel-skills training on the actual travel behavior of the trained blind traveler. Recent improvements in both of these types of measures make it feasible to do such a comparison.

This study measures the travel skills and the travel behavior of two groups of veterans from the VA Central Blind Rehabilitation Center: (i) a low vision group and (ii) a blind group. Each group's travel skills, as measured by the inter-ankle distance (ultrasonic) measuring system (IAMS) (Fig. 1), and travel behavior as measured by the Travel Inventory, will be determined at four times; twice before training, once at the end of the training period, and once 6 months after training. The relationship between travel skills and behavior will be determined for each of these five measurement points. Comparisons between the IAMS and the Nottingham group categories of mobility skills will be made. It is hypothesized that the level of travel behavior at the third and fourth measurement points will not be fully explicable in terms of the level of acquired travel skill. Factors unrelated to travel skills, such as spatial abilities and psychological stress, will result in lower travel activity than would have been anticipated from the level of travel skill ■

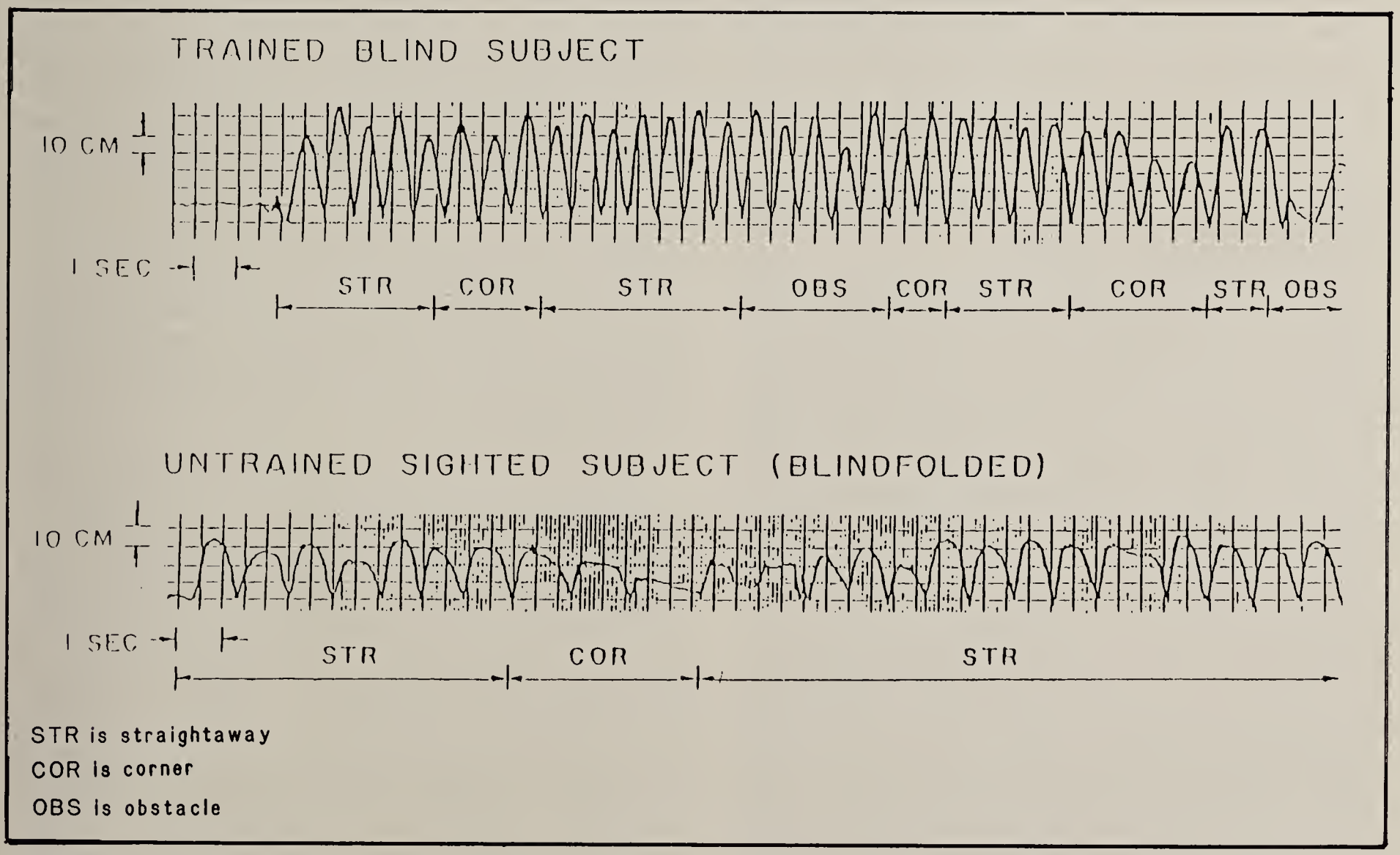

FIGURE 1
Plot of distance between subjects' ankles differs significantly when data generated by a trained blind individual is compared with data from a blindfolded sighted person. Both walked the same course, using canes to guide themselves.

READING SYSTEMS FOR THE BLIND

VA RR&D CENTER HINES

INKBRAILLE AND TACTUAL READING BY THE BLIND

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in collaboration with
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and
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The first objective of this research has been the development of rational measures for the evaluation of tactile reading performance, and the definition of an effective means for comparing alternative tactual "reading systems." A second objective has been to apply current knowledge and technology to the conceptualization and design of more efficient tactual reading systems for the blind. A third objective has been to gain a more fundamental understanding of the operating characteristics of the systems which mediate reading behavior in general and tactual reading in particular.

In our experiments we found that tactual readers appear to invoke a constant-rate text scanning strategy over a wide range of text difficulty levels. This finding has some interesting implications regarding the central neural mechanisms for processing this kind of information, and is the same finding reported for sighted reading studies. Also, we confirmed the great disparity in rates that exist between embossed braille and Optacon letter-print reading, and have initiated further studies to explore the rate-limiting effects of the several functional distinctions between these two tactual reading processes.

Inkbraille, which is a reduced-sized ink-image version of the familiar braille code, was conceived as an experimental tool, and as a potential basis for a new tactual reading system for the blind. Our initial studies of Inkbraille reading have demonstrated that embossed braille readers can readily transfer their skills to the reading of Inkbraille with the Optacon. Our results to date indicate that Inkbraille readers read Inkbraille cells at about the same rate as they read letters. This observation suggests that the poor performance of Optacon readers is related to aspects of the instrumentation and/or the Optacon reading process.

In an attempt to more closely approximate embossed braille reading, with its relatively fast reading rates, we are currently designing a device (the Inkbrailler) that will electronically generate a tactile braille cell when Inkbraille is scanned. It is hoped that this device will enable the blind to read at rates approaching those of embossed braille.

Assuming that Inkbraille and the Inkbrailler facilitate acceptable rates of tactual reading, several important advantages of Inkbraille over embossed braille should be readily apparent. Inkbraille is inexpensive, durable, and simple to produce. Moreover, Inkbraille text is compact; thus, Inkbraille books of a size similar to letter-print books would become feasible ■

VA RR&D CENTER HINES

"MAGIC WAND" — THE BRAILLE TEACHER

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Despite the development of computerized voice-output reading aids for blind people, braille remains an important medium for conveying information. Many educators and rehabilitation professionals believe that without a written language like braille, functional illiteracy would increase among blind people.

However, braille is difficult to learn. Students of braille must learn a new language that is written with new symbols. The presence of a skilled teacher is almost always necessary. Self-teaching is virtually impossible. There is a great need for better ways to teach braille.

Recently, a new educational product was introduced by Texas Instruments that appears to have great potential in braille teaching. The product is called the "Magic Wand Speaking Reader". The product incorporates a hand-held optical scanner and voice synthesis. Accompanying books contain pictures, printed words, and bar code. By passing the scanner over the bar code, beginning readers can hear the printed word.

At this Center we have made a simple change to the Magic Wand books that allows blind people to use them. Transparent braille characters have been overlayed on the printed words. Raised lines have been placed around the bar code to allow easy localization. By passing the scanner over the bar code,

users can link word sounds with braille characters. This allows students to learn independently at their own pace.

This Center is now working with consumers, rehabilitation professionals, and manufacturers to develop a complete set of braille learning materials suitable for beginning readers of all ages ■

VAMC PALO ALTO

DEVELOPMENT OF A CAMERA FOR APPLICATION IN SENSORY AIDS FOR THE VISUALLY IMPAIRED

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The purpose of this work is to develop, for visually-impaired persons, an improved hand-held camera for use as the input device for a reading machine which accepts materials such as newspapers, magazines, and typewritten documents. The camera will communicate with a microprocessor which will convert the text to computer-readable form. Together, the camera and accompanying microprocessor serve as an input module to communicate with home computers or commercially available speech output devices, allowing the user to hear the output as spoken English.

Direct conversion output will include the options of stereotoner-type musical patterns, tactile output on an Optacon, and enlarged characters on a liquid-crystal, plasma, or light-emitting-diode screen display. The camera optics will have high-enough resolution and a large-enough field of view to allow the reading of print, from the quite small sizes found in telephone directories up to newspaper headlines approximately ½ inch tall.

Camera: the necessary parts for the construction of a prototype camera (the lenses, retina, shaft encoder) have been acquired, and fabrication of the initial camera and scanner has been completed.

Interface Modules: Three interfaces to output displays are ultimately envisaged. For direct conversion feedback to guide handtracking, an interface to the TSI Optacon tactile stimulator and an interface to a stereotoner-type tone output display will be available. For output to other computers or to a text-to-speech device, an RS-232 serial interface will communicate a stream of ASCII-encoded characters.

An interface board used to communicate between the industry standard multibus computer bus structure and the TSI Optacon tactile stimulator has been designed, tested, and debugged.

This same 8085-based subsystem can communicate image information in the standard stereotoner format, or in a modified format designed for tracking guidance rather than direct reading by the user. This addition to the interface is currently being designed, and various alternatives are being evaluated. The option of tonal output for tracking guidance rather than tactile output offers a large potential cost reduction for the reading system.

Work on the three tasks described here will continue independently for 2 to 3 more months, after which we will begin system integration. It is anticipated that evaluation trials will commence approximately 8 months after that. We are hopeful that the development of this camera, which can provide input to a variety of assistive devices serving both visually-impaired individuals and the normally sighted, will find a rather broad appeal. ■

NSF

IMPROVED OBJECTIVE SPEECH-QUALITY MEASURES FOR LOW-BIT-RATE SPEECH COMPRESSION

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This study proposes to develop a number of new objective measures for speech quality, and to use these measures to design improved low-bit-rate speech coding systems. The design of the objective measures will be accomplished using a large previously developed data base of 18 hours of distorted speech, and an associated data base of subjective quality results derived from the Diagnostic Acceptability Measure (DAM) subjective quality measure.

The research is divided into four basic areas. The first area is the design of improved objective speech quality measures, based on segmental preclassification of the speech signal. The second area is the development of an improved set of objective measures specifically designed to predict the parametric subjective quality results available from the DAM test. The third area is the study of an iterative technique for designing linear predictive coder (LPC) parameter quantizers subject to a complex objective quality measure. The final area consists of the design of a number of new low-bit-rate speech coders, based on the results of the other three areas.

The experimental work for this research will be performed using a minicomputer-based digital signal-

processing laboratory, a highly interactive facility specifically designed for speech and digital signal-processing research. Careful subjective speech quality tests will be performed on promising speech coders, using an automated speech quality testing facility ■

NSF

DESIGN OF VARIABLE-RATE, SUBBAND CODED SPEECH ENCODING USING VECTOR QUANTIZATION

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This research project is concerned with low-rate speech communication systems using vector quantization. Good fixed-rate and variable-rate vector codes will be designed, using full search or tree-searched schemes on waveform encoding and on linear predictive speech-coding problems. The design of variable-rate subband coded vector quantization of speech samples will be investigated. Special emphasis will be given to the development of algorithms, and to the design of systems, with computational simplicity, fast convergence, robustness against channel errors, and cost effectiveness, to make them amenable to implementation ■

LOW VISION

VA RR&D CENTER HINES

SIMULATION OF RESIDUAL VISUAL FUNCTION

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A large portion of the nation's 2.5 million legally blind people have some residual vision. Many remedial devices and techniques have been developed to allow these people to function well despite their disability. Despite those efforts, experts in low vision generally agree that present training methods and aids are inadequate. This failure may be partly attributed to the tests used for assessing visual function.

The tests now commonly used in low vision clinics include: visual acuity, visual fields, depth perception, and range or accuracy of eye movements. Ironically, although these tests tell us something about the quality of a person's vision, they may not tell us about his ability to perform complex visual tasks. There is a definite need for tests that provide this knowledge. These tests could be used to guide remedial training, specify designs for optical aids, or study the sensory or cognitive processes of visually-impaired people ■

VAMC ATLANTA

ELECTRONIC TYPEWRITER FOR THE VISUALLY IMPAIRED

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The Electronic Typewriter is a generic equivalent of cassette-braille machines designed for large-print users. The system features a large-print display and a typewriter keyboard with microcassette storage of information.

Progress — Construction of three prototype test units is proceeding. One of them will have large-print CCTV output as well as a vacuum fluorescent display. The system has been designed as an electronic add-on to the Sony Typecorder and is plug-compatible with the Sony LCD display. The system under construction already has RS-232 serial interface to allow communications with common computer equipment. The display utilizes an 8741 microprocessor.

The first unit is functioning and has been sent to an interested potential manufacturer. Additional units are being constructed and work is beginning on the CCTV interface.

Recently the new Epson HX-20 microcomputer has become available and it is being considered as a replacement for the Typecorder, which has only one-way communication and is essentially a dedicated word processor. The Epson is being evaluated to determine if it has sufficient capabilities to warrant modification for this application.

Future plans — Construction will continue for the next 3 months and lead into field evaluation of the units after that time. Initial contacts have been made with potential interested manufacturers and the research team is working closely with these to evolve a production-ready prototype ■

VAMC ATLANTA

GUIDE-DOG HARNESS DESIGN

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This is a student design project. The purpose is to design and test new guide-dog equipment with a more appropriate choice of materials technology. The goal is to develop a harness and leash that have better wear, less care required, superior esthetics, and lower production cost.

Progress — The first prototype is almost complete and testing will begin within 30 days. Nylon has been chosen as the main material to be used and acrylic rods will be used for the handle. All buckles will be replaced with Scotch Mate, and other metallic hardware will be minimized.

Future plans — Plans are to develop several prototypes and cooperate with interested guide-dog schools in testing the units. Several schools have expressed interest in testing the new equipment and have generously provided excellent recommendations and marketing data. A potential manufcturer has been located and production is expected to follow successful testing ■

SYSTEMS FOR THE HEARING IMPAIRED

VAMC MARTINEZ

SENSORINEURAL HEARING LOSS: FREQUENCY DISCRIMINATION, INTENSITY-RESPONSE FUNCTION, & BINAURAL DIPLACUSIS

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The purpose of this research program is to characterize the suprathreshold auditory function of an individual with sensorineural hearing loss (SNHL) by means of a theoretical model of pitch processing (Yund and Efron, 1977), and then to use that characterization to design a signal-processing system to compensate for that hearing loss. If the results indicate that the model is useful in designing compensation systems (hearing aids) for SNHL subjects, the next phase of the research will be the adaptation of these methods to the clinical setting.

Frequency Discrimination — The study of frequency discrimination in SNHL patients has a dual role in this research program.

In the first respect, it is essential to establish that SNHL does not consistently degrade the ability of the auditory system to process frequency (pitch) information. If a large degradation of the information carried in the frequency domain were an integral part of SNHL, this would indicate not only that the Yund-Efron model could not be applied to SNHL, but that any idea for improving the design of hearing aids faced the virtually impossible task of recovering information which is not just distorted in some regular way, but instead is entirely lost.

Secondly, it is important to determine whether the frequency information in any particular band in either ear of a patient is degraded. If only one ear shows degraded frequency information in a particular band, information in that band can be delivered only to the other ear. Alternatively, if neither ear can process frequency information in a particular band, it may be better to eliminate sound energy in that band from both ears rather than include information that cannot be processed accurately. (This would be an empirical question to be answered individually for each subject.)

Frequency discrimination was measured in the left and right ears of 15 SNHL subjects at as many as possible of the frequencies: 500, 750, 1000, 1500, 2000, 3000, and 4000 Hz. While the poorest frequency-discrimination performance generally occurred where subjects had a significant threshold elevation, the relationship between discrimination performance and intensity threshold was not a very close one. Comparing the performance between the two ears of the same subject indicates that the superior discrimination is not always in the ear with the lower intensity threshold at that frequency, and furthermore, that large differences in frequency discrimination (up to an order of magnitude) may be found in the absence of any difference in intensity threshold.

Data indicate that frequency-discrimination and intensity-threshold deficits are essentially independent, and furthermore, that the frequency discrimination deficits found in SNHL subjects often occur in only one ear or in different frequency bands in the two ears.

Intensity-Response Function — The current reporting period has been devoted to increasing the subject population and, more importantly, to solving two problems which have occurred in attempts to measure I-R functions in some subjects. Specifically, (i) a greatly reduced dynamic range accompanied by recruitment, or (ii) binaural diplacusis at the test frequency. In the case of a greatly reduced dynamic range accompanied by recruitment, the slope of the I-R function is changing very rapidly with intensity. Under these conditions, small variations in stimulus intensity caused by variations in positioning of the standard headphones become significant. Using insertion earphones instead of the standard headphones eliminates intensity variations and thus reduces the measurement variability to the level normally encountered in such measurements. Binaural diplacusis at the test frequency may or may not be accompanied by a frequency discrimination deficit in one or both ears. If a major frequency discrimination deficit is present at a test frequency, the I-R function measurements are done at a nearby frequency where no such deficit is found. If, on the other hand, binaural diplacusis occurs with no discrimination deficit, frequency corrections for the diplacusis are incorporated into the I-R measurement procedure.

Binaural Diplacusis — Some of our SNHL subjects, however, show a binaural diplacusis of more than 10 percent. Such a large difference in the perception of the same frequency information depending upon the ear to which it is delivered might cause considerable confusion in the more natural situation where the two ears usually receive a very similar array of frequency information. At the present time, the significance of binaural diplacusis in producing a functional deficit in the SNHL patient in unknown. We will study the role of binaural diplacusis in SNHL by introducing compensation for the diplacusis (in addition to the compensation for the I-R function) into stimuli delivered to our SNHL subjects, and determining the extent to which that diplacusis compensation improves the SNHL subject's binaural hearing ■

VAMC NASHVILLE

THE MODULATION TRANSFER FUNCTION AS A PREDICTOR OF SPEECH INTELLIGIBILITY

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The overall objective of this project is to evaluate the effectiveness of the modulation transfer function (MTF), and the speech transmission index (STI) derived from the MTF, as a predictor of speech-recognition performance in hearing-impaired listeners.

There are three phases to this project. In the first phase, the acoustical MTF is measured, the STI calculated, and speech-recognition performance assessed, for a variety of listening conditions including: (i) filtered speech; (ii) additive noise; (iii) reverberation; (iv) filtering-plus-noise; and (v) reverberation-plus-noise. Speech materials include the Nonsense Syllable Test or NST, the Speech Perception in Noise or SPIN test, and Northwestern University Auditory Test No. 6 or the NU-6 test.

In the second phase of this project, conducted in parallel with the first phase, a psychophysical corollary of the acoustical MTF is explored. This measure, known as the psychophysical modulation transfer function (PMTF), would permit prediction of an individual listener's speech-recognition performance, as opposed to prediction of average performance for a group of listeners. This experiment makes use of the temporal probe method (5) to measure the PMTF. The PMTF is measured at 0.5, 1.4, and 4.0 kHz in quiet, broad-band noise and in high-pass noise. Speech-recognition scores for the SPIN and NST were then obtained under the same conditions.

The third phase of this project will be initiated in early 1984. In that phase, acoustical MTFs will be obtained from a variety of hearing aids and the STI calculated ■

VAMC TEMPLE, TEXAS

DEVELOPMENT OF STIMULUS MATERIALS FOR COMPUTER-ASSISTED INSTRUCTION IN LIPREADING

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The purpose of this project is to increase the effectiveness of lipreading instruction for hearing-impaired adults. Computer-assisted instruction (CAI) is being examined as a way of providing systematic supplementary drill and practice in lipreading for postlingually hearing-impaired adults.

Instrumentation for Computer-Assisted Instruction in Lipreading — The present system being used for presenting drill and practice sentences via computer-assisted instruction in lipreading consists of the DAVID Instructional System (Vontech, Inc.), Coulbourn Instruments Programmable Attenuator and accessories, and a Grason-Stadler 1701 Clinical Audiometer.

Drill and practice sentences are programmed in Vontech Authoring Language to provide two kinds of redundancy which accompany the visual presentation of the lipreading stimulus. In the linguistic redundancy condition, the first presentation of the lipreading stimulus is presented with no clues. If the lipreader does not identify the sentence correctly, the next video presentation is preceded by markers on the subject's CRT which indicate the number of letters in each word and the number of words in the sentence. After the third presentation, the CRT displays a clue word to the side of the markers, that is, a word is shown out of context. The fourth presentation of the lipreading stimulus is followed by one clue word in context along with the previously shown markers. The fifth and final presentation provides two clue words in context. If the lipreading student has not identified the sentence completely correctly by the fifth trial, the videotape is advanced to the next sentence.

In the auditory redundancy condition, the first presentation of the lipreading sentence is displayed without clues. If the student does not lipread the sentence completely correctly, the second presentation is accompanied by an auditory signal level at 0 dB sensation level re speech-noise detection threshold. If the student continues to need additional increase in the auditory signal level for correct identification of the sentence, the third visual presentation is accompanied by a 5-dB sensation level of the auditory signal. The fourth trial has a 10 dB sensation level, and the fifth trial has a 15-dB sensation level.

The effects of two conditions of redundancy will be examined in terms of their effect on the development of lipreading skill as lipreading students are provided formal lipreading instruction and supplementary drill and practice in computer-assisted instruction in lipreading.

Problems Requiring Resolution — Two primary problems have been encountered which make the ¾-inch videocassette player inappropriate for computer-assisted instruction in lipreading. The first problem is tape slippage with resultant inaccurate accessing of video frames.

Other Activities — Other research activities in this project have included the construction of consonant-vowel-consonant (CVC) words in preparation for the development of procedures for presenting minimal viseme contrasts in lipreading instruction. A thorough examination of the historical background of lipreading has been conducted and a manuscript summarizing this research is in preparation. Twelve 1-hour lipreading lessons have been prepared for formal lipreading instruction, which is a part of this project. Finally, a comprehensive bibliography of literature references on lipreading and topics related to aural rehabilitation of postlingually hearing-impaired persons has been a continuing effort ■

NSF

TACTILE PERCEPTION OF SPEECH

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The major objective of this project is an examination of the feasibility of using the tactile sense as an alternate modality for the perception of speech and the understanding of spoken language. We therefore address two major questions that are fundamental to this program: first, how should the distinctive elements of the acoustic speech signal be transformed to provide recognizable tactile patterns; and second, what is the most effective training procedure for perceptual learning of tactile speech displays and for evaluating various tactile representations of speech?

We will present natural and synthetic speech tokens to the skin of the finger(s) using a computer-controlled spectral display and Optacon transducers. We will also develop and evaluate training procedures for the acquisition of tactually presented speech. A novel training paradigm will be examined: it takes advantage of the close association between speech production and speech perception by allowing the learner of tactile speech to produce, hear, and feel his or her own speech patterns in real-time. This paradigm will be used, initially, in conjunction with experiments on the utility of combining tactual information with visual information during speechreading. The results of these experiments should have broad implications for the development and improvement of speech aids for the deaf and aids for both perception and production of speech ■

NSF

USE OF VOICE-TO-TEXT IN DEAF-HEARING DIALOGS

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This research explores methods of coupling voice-to-text (VTT) conversion technology with speech synthesis devices, to allow better communication between the deaf and the hearing.

The research specifies, demonstrates, and evaluates VTT systems that are practicable and useful in dialogues between a hearing person talking over a phone to a deaf person who is typing.

Specific research tasks are to:

1. Define the necessary system parameters of a usable VTT system, including the level of recognition performed by machine, the degree of accuracy of machine operation, and the amount of training required by deaf and hearing persons;
2. Demonstrate an operational system coupled to the phone network;
3. Determine the extent to which deaf users can provide their own syntactic and semantic analyses; and
4. Identify key research problems that require solution.

Experiments, conducted to simulate communication between deaf and hearing persons, include simple information-transfer tasks as well as fully interactive representative dialogs.

This is the first year of a 3-year continuing award ■

NSF

PRODUCTION AND VISUAL ARTICULATORY SHAPING OF SPEECH IN DEAF CHILDREN

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The goal of this research is to bring new scientific and engineering developments to bear on understanding and improving speech production of deaf children. Four lines of investigation are underway:

First, using a new computer-based instrumentation system, a complete physiologic, acoustic, and phonetic description of speech production by 6 to 14 year old deaf and hearing children is being developed. These data are being used to identify contrasting patterns and strategies of speech production and to investigate relationships between articulatory visibility and proficiency.

Second, visual displays and monitoring devices are used to study lip, jaw, and tongue control in articulator positioning and in manipulating forms within the mouth. These data are being interpreted from a sensory deprivation viewpoint.

Third, static and dynamic visual articulatory displays are used to study recognition of English sounds through vision.

Fourth, the efficiency and effectiveness of visual articulatory displays for monitoring the speech of others, and changing one's own articulatory patterns, are being explored.

In all of this work, the ultimate goal is to develop an accurate, internalized, conceptual schema using vision to specify articulatory targets and guide movements to and from such targets in three-dimensional space. It is expected that this research will contribute substantially toward solving the imposing speech difficulties of deaf children ■

NSF

VOCAL FOLD VIBRATION AND SPEECH

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This study is concerned with describing the role vocal-fold vibratory motion plays in the production of speech. Basic speech models use the source-filter theory, which claims that the vocal folds modulate the air expelled by the lungs and that modulated

air excites the vocal tract to produce voiced sounds. But little is known about how the motion of the vocal cords affects the quality of speech production. Our proposal is studying this aspect of laryngeal function.

The proposal methodology includes the comparison of data obtained from synchronized ultra-high-speed laryngeal films, electroglottograph (EGG) waveforms, and recorded speech signals. We measure and compare parameters of vibratory vocal fold behavior from these films, EGG, and speech signals. This data is being used to develop new real-time speech processing techniques. The most significant parameters of vocal fold motion which contribute to reproducing or synthesizing the original speech are being determined.

The results of this study will assist us in developing training aids to assist the deaf or hearing-impaired to speak more naturally. Our results would also be useful for teaching foreign languages. We are using our findings to produce more natural-sounding synthesized speech, and to describe the differences between male, female, and children's voices ■

NSF

AUTOMATIC MEASUREMENT OF LARYNGEAL VIBRATORY PATTERNS

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This study is directed toward establishing a relationship between parameters of vocal cord motion, as measured from ultra-high-speed laryngeal films and from acoustic parameters extracted from audio recordings of phonation, obtained simultaneously, during the laryngeal filming process. The specific goal is to quantify and relate aspects of laryngeal vibratory motion by processing ultra-high-speed laryngeal films and simultaneously recorded phonations.

The quantified parameters will be studied to establish the relationships between the many factors in laryngeal vibratory motion, and both fundamental frequency and sound intensity. The results of the study will contribute to understanding of the manner in which the motions of the vocal folds are transformed into the unique sound generated.

No human subjects will be involved in the study, since the data are already available from a normal subject population with a normal organ for voice production and normally functioning vocal cords. The unprocessed data are in the form of ultra-high-speed laryngeal films (on the order of 5,000 frames/sec) and sustained phonations simultaneously recorded during the filming process.

This research is part of an overall program of "Science and Technology to Aid the Physically Handicapped" and may contribute eventually to the design of better machine aids for teaching speech to the deaf ■

VAMC TEMPLE, TEXAS

INVESTIGATION OF ACOUSTIC REFLEX IN ELDERLY PERSONS

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Work through June 23, 1983, included two normative investigations of the contralateral acoustic reflex, and completion of rudimentary software for communication between a host computer and a digital acoustic-immittance instrument.

Both investigations used subjects with normal hearing sensitivity. One investigation concerned adaptation of the acoustic reflex response, measured in aural acoustic immittance with an analog acoustic-admittance instrument interfaced to a computer (Nicolet 812). Reflex-activating signals were four pure tones and broadband noise. Subjects were within the 20–79 year age range. Major results were —

1. That the rate of adaptation was greater for one acoustic admittance component (susceptance) than the other (conductance);
2. That the 2000-Hz signal provided the earliest onset of adaptation; and
3. That maximum response amplitude, and slope of adaptation, were related to subject age.

The other investigation concerned the effect of activating-signal bandwidth on the input-output function of acoustic reflex. Signals were three pure tones and bands of noise centered geometrically around each tone (octaves of 0.33, 0.5, 1.0, and 2.0). Subjects were young adults. Results indicated that slope of the input-output function was not clearly related to signal bandwidth, and could be predicted by static admittance plus the reflex response of largest amplitude.

Progress has also been made on development of host computer software for control of a digital acoustic-immittance instrument. Preliminiary calibration and assessment of the digital instrument has been completed and sufficient software has been written for acquisition and storage of data in an investigation of acoustic reflex latency. Additional control software for the acoustic-immittance instrument is planned during FY84 ■

SPEECH TECHNOLOGY

NSF

PARALLEL ARCHITECTURES FOR SPEECH RECOGNITION

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The advent of Very Large Scale Integration (VLSI) has made feasible the development of new computer architectures and algorithms, as well as the exploration of older ideas previously not pursued because they were too costly to implement.

Speech recognition is a computationally intensive technology which stands to gain widespread use through VLSI. There is a need for experimentally based research into the integrated problems of computer architecture and associated algorithms. A focus of this study is the development of new approaches for economical implementation of new intelligent algorithms. The research examines the design and implementation of multiprocessors computing systems (composed of microprocessors) for these new and more intelligent discrete utterance recognition (DUR), connected speech recognition (CSR), and digital signal processing algorithms.

The best recognition algorithms, currently only in the most expensive speech recognition systems, are "brute force" and costly to implement. Past work by the principal investigator has shown how one can reduce computational costs by an order of magnitude without loss in accuracy. Research is continuing on new algorithms which will allow large-vocabulary DUR, and better CSR, to be put into economical multiprocessor systems. It is intended to implement these new ideas to the stage of prototype hardware and software, and evaluate these in a real-time computing environment through carefully designed experiments ■

NSF

PARALLELISM IN SPEECH PROCESSING

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The objective of this research is the study of the parallelism in speech-processing tasks and how this parallelism can be exploited by large-scale multiprocessor systems. Both parallelism within a task, and parallelism among tasks, will be investigated for a variety of specific important speech processing problems. Algorithms based on the SIMD (single construction stream — multiple data stream) and on multiple-SIMD modes of parallelism will be developed and analyzed.

A set of time complexity equations for evaluating the execution of a set of tasks on a partitioned multiple-SIMD system, in terms of parameters such as the number of partitions, the size of the partitions, the time for intra- and inter-partition communications, and instruction speech will be derived. The features needed to express parallelism in a high-level language for parallel speech processing will be evaluated.

The design of highly parallel asynchronous architecture for speech understanding, based on the use of parallel subsystems to construct a virtual nondeterministic machine, will be explored. It will incorporate SIMD, multiple-SIMD, and special-purpose processors as components.

This research is expected to advance the state-of-the-art of both parallel processing and speech processing. It will aid researchers in these areas to exploit the parallelism of the large-scale multiprocessor computer systems of the 1980's ■

SPEECH IMPAIRMENT APHASIA

VA RR&D CENTER PALO ALTO

GRAPHIC COMMUNICATION ENVIRONMENT

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GraphCom is an interface which is easy to use, can grow with the user, and offers assistance in presenting and organizing information. Because a computer is helping to control the system, it will be able to provide training and prosthetic assistance to the user. GraphCom is a non-text communication medium that helps the user manipulate images and construct mnemonic drawings to convey meaning. The interface requires only that the user be able to understand physical objects in the outside world.

Status — The GraphCom project is proceeding in two stages. In the first stage, the existing software has been installed at the Palo Alto Rehabilitation

R&D Center. The second stage is to extend that software to measure and assist the performance of cognitively disabled users. This stage is approximately 20 percent complete ■

VAMC BIRMINGHAM

EFFICACY OF REMOTE DELIVERY OF APHASIA TREATMENT BY TEL-COMMUNICOLOGY

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Audiology-Speech Pathology Service (126)
Birmingham, Alabama

Purpose — The purpose of the project is to compare the efficacy of two methods of delivery of an aphasia treatment program by (i) remote TEL-Communicology, involving both clinican and computer-assisted delivery, and (ii) face-to-face delivery of the same program. The long-term objective of the project is to determine whether TEL-Communicology is efficacious, cost-effective, and makes quality health care more available and accessible.

Experimental Results — The data collected will be used to accomplish the following primary purposes: (i) to determine the rate and amount of improvement in aphasia (comparison of intake performance with performance after 6, 12, 18, and 24 weeks of treatment), and (ii) to compare the performance of the two methods of treatment delivery: Group 1 using face-to-face clinic delivery and Group II utilizing TEL-Communicology.

Accomplishments — Between February 1 and June 30 of 1983, 14 subjects qualified for the project. As of June 30, no subject had completed the 6-month treatment period. Of the 14 participants, random assignment placed 7 subjects in the face-to-face delivery group, and seven subjects in the TEL-Communicology delivery group.

The comparison of the cost performance of the face-to-face and TEL-Communicology delivery systems is in progress ■

*Of the four Veterans Administration Medical Centers cooperating as treatment centers in this project, Birmingham also serves as Project Center and is responsible for scoring videotaped subject evaluations, compilation of data, and training of all personnel. Dr. Vaugn is Chief of the Audiology-Speech Pathology Service at Birmingham VAMC.

VAMC MARTINEZ

A TACTILE AID FOR THE TREATMENT OF SENSORINEURAL HEARING LOSS AND APHASIA

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This investigation is designed to test the efficacy of Teletactor, a wearable electrotactile sensory aid, as a treatment for speech discrimination deficit in severe sensorineural hearing loss, and auditory comprehension deficit in severe aphasia. Worn as a belt across the abdomen, Teletactor converts an auditory signal into electrical impulses and presents these as electrotactile patterns on the skin. A 20-week controlled treatment trial is being conducted to compare performance by patients with severe sensorineural hearing loss, and performance by patients with severe aphasia, when wearing Teletactor with performance to when not wearing Teletactor.

During the period from January 1, 1982, through June 30, 1983, we have completed the assembly of a computer system to generate and present acoustic stimuli and record patient responses ■

Reports from Other Nations

Prosthetics/Amputation R&D

LOWER LIMB PROSTHETICS

AIST (JAPAN)

ACTIVE ARTIFICIAL LEG

National Research and Development Program for Medical and Welfare Apparatus
Agency of Industrial Science and Technology
Ministry of International Trade and Industry
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The artificial leg being developed in this program is equipped with a drive unit ("rotary actuator") to the knee and the ankle, and sensors at the sole. Motorized devices are also being developed that will enable the user to stand up, crouch, keep a half-rising posture, walk on level ground, walk on a rough road, etc. The first prototype has been tested ■

STRATHCLYDE

A SYSTEM FOR MEASURING LOWER LIMB PROSTHETIC LOADINGS DURING OUTDOOR ACTIVITIES

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A prosthesis must be of strength adequate to withstand the loads applied to it by the patient during various activities. The prosthesis should also have a low mass, to allow low energy expenditure by the patient. To obtain a compromise between these two conflicting factors of strength and mass, it is necessary to obtain accurate information of the loads applied to a prosthesis in the course of daily activities.

At the University of Strathclyde, a system employing a six-channel strain-gaged pylon transducer and knee-angle electrogoniometer has been used for several years to study amputee loading patterns. The pylon transducer itself was designed to be as short as possible in order to accomodate the majority of below and above knee amputees. Using this system, loading data for design and mechanical testing purposes have been accumulated. The results were used in the formulation of the "Standards for Lower Limb Prostheses" (Philadelphia 1978, ISPO publication). The multichannel cable, which is used to connect the transducer to the bridge amplifiers and associated electronics, has, however, restricted the subject to the confines of the laboratory. In order to investigate amputee activities outdoors, it was necessary to eliminate this umbilical cable. This was done by recording the transducer signals on a specially built eight-channel portable system which can be carried by the amputee. The system utilizes standard C120 cassette tapes and allows an uninterrupted recording time of 1 hour outside the confines of the laboratory. A custom-built playback unit allows analysis of the results. The system has been used over the last year on amputees, and the effect of different types of terrain on limb loading has been studied.

Financial assistance for this project was received from the Scottish Home and Health Department ■

STRATHCLYDE

BIOMECHANICAL EVALUATION OF SACH AND UNIAXIAL FEET

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Biogengineering Unit
Wolfson Centre
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A review of prosthetic prescription practice reveals that in Britain about 80 percent of below and above knee amputees are fitted with uniaxial feet, whereas in the United States, about 80 percent are fitted with SACH feet. Although subjective studies to compare the two types of feet have been carried out, only limited attempts to acquire comparative objective data have been reported.

In this work, an evaluation method was developed to assess the performance of the two feet. It includes a subjective assessment procedure and a biomechanical evaluation of the function of the two feet and their effects on whole-body kinematics and lower limb kinetics. A suite of computer programs has been devised to facilitate the calculation of the results. Data are acquired by three Bolex H16 cine cameras and two Kistler force plates. This set-up allows three-dimensional analysis on the prosthetic and contralateral sides of the subject.

The investigations undertaken permitted the interchange of the ankle/foot in the experimental prosthesis without changing the rest of the components. Six below-knee and five above-knee amputees have been studied. No clear trend of preference for either type of foot was evident from the subjective survey; in general, the patients showed a preference for the foot to which they were accustomed. The kinematic and kinetic analysis, however, showed differences in function between the two prosthetic feet. It was found that the movements of the uniaxial foot were much closer to the movements of a normal foot than were those of a SACH foot. On the other hand, the load patterns at the ankle of the SACH foot were closer to those of the normal foot. A full report describing the evaluation methodology and significance of the results is being prepared for publication at a later date ■

STRATHCLYDE

BIOMECHANICS OF HIGH STRESS LOWER LIMB ACTIVITIES

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The load actions to which the lower limb joints are subjected during stressful activities are investigated. Healthy volunteers perform tasks including walking, running, hopping, long jump, squat thrust, jump down, and twisting turn. Two Kistler force platforms record the ground reaction forces and moments, and synchronised three-dimensional cine film data allow the calculation of ankle, knee, and hip moments. Care is taken to reduce variability of the performances, and initial results indicate good repeatability.

Several calculations of the joint structure loadings suggest that joint surfaces and ligaments must transmit greatly increased loads (20 percent to 100 percent) from those encountered during normal level locomotion. Results should be published in late 1983 ■

STRATHCLYDE

STUDY OF ALIGNMENT IN LOWER LIMB PROSTHESES

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Alignment of a prosthesis is defined as the position of the socket relative to the foot and other components. During dynamic alignment the prosthetist, using subjective judgment and feedback from the patient, aims to achieve the most suitable limb geometry for best function and comfort. In the past, it was generally believed that a given patient could be satisfied only with a unique "optimum" alignment. However, work carried out at the University of Strathclyde showed that a patient's requirements may be satisfied by any one of several alignment configurations. (Solomonidis 1980).

The purpose of this project is to carry out a systematic study in order to establish the range of acceptable alignment and to understand the patient's tolerance in relation to dynamic alignment. It also aims to investigate the effect of alignment variation on amputee gait.

Twelve below-knee (BK) and 12 above-knee (AK) active amputees are being studied. Five experienced

prosthetists are carrying out several alignments of each subject under clinical conditions on several occasions. Following dynamic alignment, the prostheses are accurately measured using custom-built apparatus. A six quantity load transducer is incorporated into the shank of the prosthesis, and force platforms are utilized for acquisition of loading data. Three-dimensional cine and TV systems, together with goniometry, are employed for the collection of kinematic data. Much of the experimental data has been collected and analyzed. Interpretation of the data has proved time-consuming, due to the complexity of the problem and the interaction of many parameters. Examples of typical findings are as follows:

For a certain BK patient fitted 19 times, the anterioposterior (A/P) socket tilt varied from 1 to 11 degrees and the A/P shift from 0.4 cm to 2.4 cm.

For a given patient, two different but perfectly acceptable alignments resulted in considerable quantifiable changes in gait characteristics. For instance, one alignment caused an AK amputee to exert a maximum moment by the hip extensors 30 percent greater than necessary for the same prosthesis using a second alignment. Similarly, compensation by the contralateral side can show a 50 percent change in moment values at the hip from one alignment to another.

Financial assistance for this project was given by the Scottish Home and Health Department ■

ORTHOTICS

STRATHCLYDE

ENHANCEMENT OF LIMB FUNCTION BY MEANS OF FES

Principal Investigators: B. J. Andrews, J. P. Paul, C. M. van Griethuysen, and **G. Day**
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New areas of application for FES are being explored alongside more traditional orthotic methods used for locomotion and upper limb function. The following is an outline list of our present projects:

A programmable stimulator has been developed that allows a double-blind evaluation of the effectiveness of various waveform parameters. This stimulator enables any set of waveforms to be applied in a randomized sequence. A dynamometer system has also been developed so that the generated muscle force actions may be recorded. Our present studies relate to student volunteer subjects. However, studies will be extended to subjects with various neurological disorders in the near future. This project is funded in part by the Medical Research Council (UK).

A microcomputer system has been developed for controlling the application of biofeedback and FES combinations to enhance upper limb function. Biofeedback data presentation is derived from orthotic splints instrumented with goniometers. Present studies relate to wrist/elbow function for cerebral palsied children and hemiplegic adults. The project will be extended to include other neurological disorders. Ultimately, it is envisaged that a small body-worn system will be produced for everyday use. This project is funded by the Action Research for Crippling Diseases (UK).

An active hand-extension orthosis is under development for application following hand surgery. The system maintains cyclic hand mobility in the postoperative period and aims to prevent formation of tendon adhesions and to reduce edema.

Closed-loop joint control and spasticity regulation systems are being investigated. These projects aim to develop enhanced orthotic devices for upper and lower limb function. This project is funded by the Multiple Sclerosis Society (UK) ■

STRATHCLYDE

LOAD ANALYSIS OF KNEE-ANKLE-FOOT ORTHOSES

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Wolfson Centre
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Knee-ankle-foot orthoses currently being prescribed to patients are reported as heavy and cumbersome. Despite their apparently robust construction, failures frequently occur, indicating that the design is unsatisfactory. Strength and mass are thus interrelated parameters between which a compromise must be reached if an effective device is to be obtained. Furthermore, the proportions of the total load being taken by an orthosis have apparently not been evaluated. These can be influenced by the fitting technique employed by the orthotist.

The purpose of this study is to measure and analyze the loads acting on the orthosis and the patient's limb during ambulation. Orthosis loading data are acquired by means of custom-built equipment consisting of four multicomponent load-measuring transducers, amplifiers, and a multiplexer. By simultaneous recording of ground-to-foot forces and body movements, the proportion of loads carried by the affected limb may be derived.

From the work carried out so far, it is evident that the maximum anterioposterior bending moment of ± 18 Nm, recorded on the orthosis during level walking, constitutes a critical type of loading. Stress calculations indicate that a load of this magnitude can lead to premature fatigue failure.

Financial assistance for this study was given by the Scottish Home and Health Department ■

DERBY O&DRC (GT. BRITAIN)

THE DEVELOPMENT OF MECHANICAL TESTS FOR ORTHOPAEDIC CALIPER KNEE JOINTS

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Orthotics and Disability Research Centre
Derbyshire Royal Infirmary
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This 3-year research project sponsored by the Department of Health and Social Security aimed to provide useful information regarding the development of a British Standard on caliper knee joints. The project looked at the wear and development of rotational free play in bale lock and ring lock calipers and the four point bending properties of the same joints.

The results of excessive mechanical wear of caliper knee-joint lock mechanisms can be disastrous, as the patient relies completely upon the support provided by the locked hinges. Wear rigs were designed to lock and unlock two types of joint whilst in the presence of small induced preloads in the lock during opening. This situation was found to best represent the environment in which the hinges were actually used. The rigs were pneumatically controlled and took the general form shown in Figure 1.

The caliper arm to the left of the pivot was clamped firmly whilst the right-hand arm remained free to rotate about the pivot and was only retained in the horizontal position by the pivot lock. The slight contact pressure between the sliding surfaces of the lock was maintained by the dead weight resting upon the end of the caliper. Due to the tendency for the free arm to swing downwards once the pivotal lock was released, provision was made for raising both the bar and the weight to enable the pivot to be re-locked and the weight to be reapplied.

The wear was monitored optically using the autocollimator principal which allows accurate measurement of rotations of the order of one minute of arc. Though tests were conducted upon both the ring and the bale lock, the latter suffered appreciably more surface damage than the ring lock and therefore a greater proportion of the report was devoted to the bale lock.

Figure 2 shows the wear curve for a large bale lock and it will be noticed that the wear rate reduces significantly after an initial period of very rapid wear. It seems likely that this transition is associated with the eradication of the breached furrows. It is difficult to determine any direct relationship between the magnitude of the applied load and the level (in terms of minutes of arc) at which this transition took place. Certainly for the medium lock the transition points

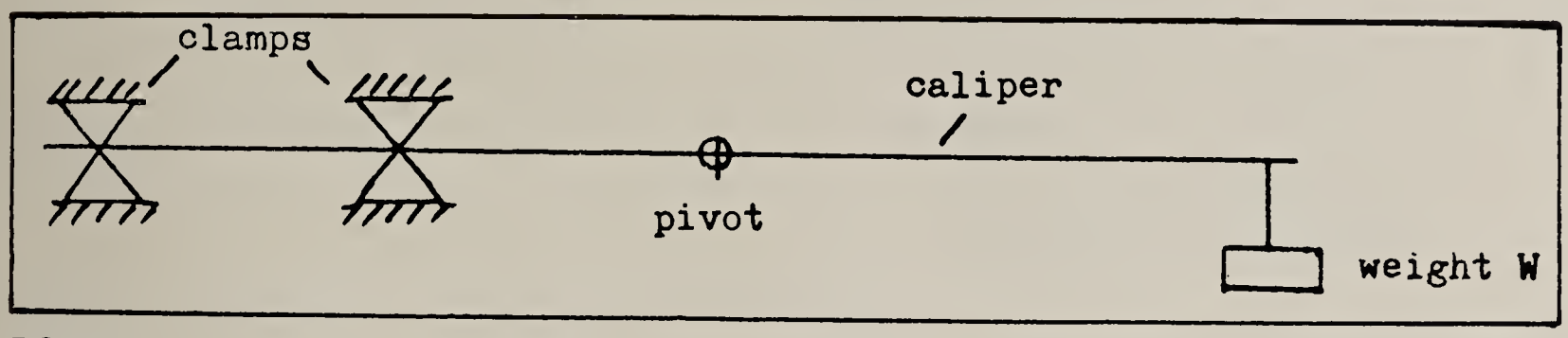


FIGURE 1
Sketch of the general form of the pneumatically controlled wear rig used to lock and unlock a knee-joint mechanism in the presence of a small induced preload in the lock during opening.

do appear to be higher than those of the large bale lock. This suggests that the higher contact stresses due to the smaller area of the medium bale may be responsible. This evidence, and the considerable scatter within groups, suggest that it is the mechanical properties and surface finish which determine the magnitude of the damage.

There was considerably less surface damage to the sliding faces of the ring lock and, at the very most, the growth in rotational free play was only some 25 minutes of arc. Figure 3 is the result of a series of tests upon MASSER ring locks, and once again there is no apparent connection between the wear rate and applied loads. Loads were deliberately applied in excess of those likely to be encountered in service, to see if there was any adverse effect upon the wear rate. There was, however, no marked increase in the wear rate for this particular joint, and in fact, for most of the joints the increase in free play was less than the free play already present before the tests commenced.

The "in service" loading of a caliper joint is as yet unknown, but the major component is most likely to consist of a bending load; axial and torsional loading may also be present but any attempt to model a complex loading system would only hinder the interpretation of the results and make comparisons between different designs difficult. Therefore, a rig designed to apply pure bending moment across the face of a caliper lock (consisting, essentially, of a modified four-point bending arrangement) was fitted within a standard tensile testing machine. Record-

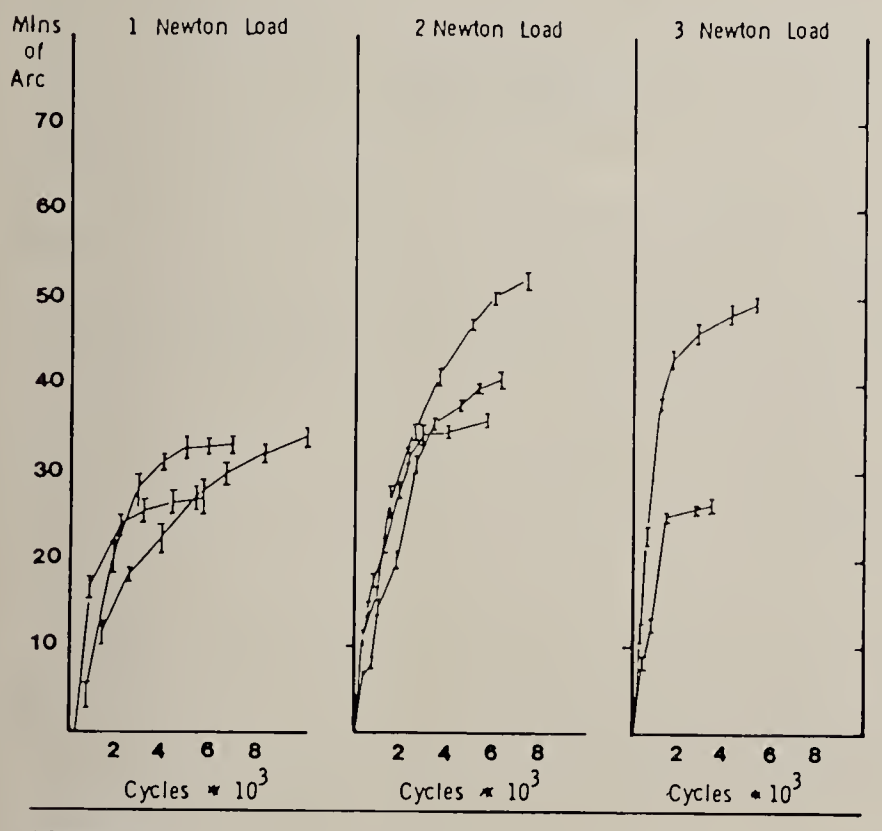


FIGURE 2
The growth of rotational free play in a large bale lock for a range of applied loads. Rate of wear reduces significantly, the authors note, after an initial period of very rapid wear.

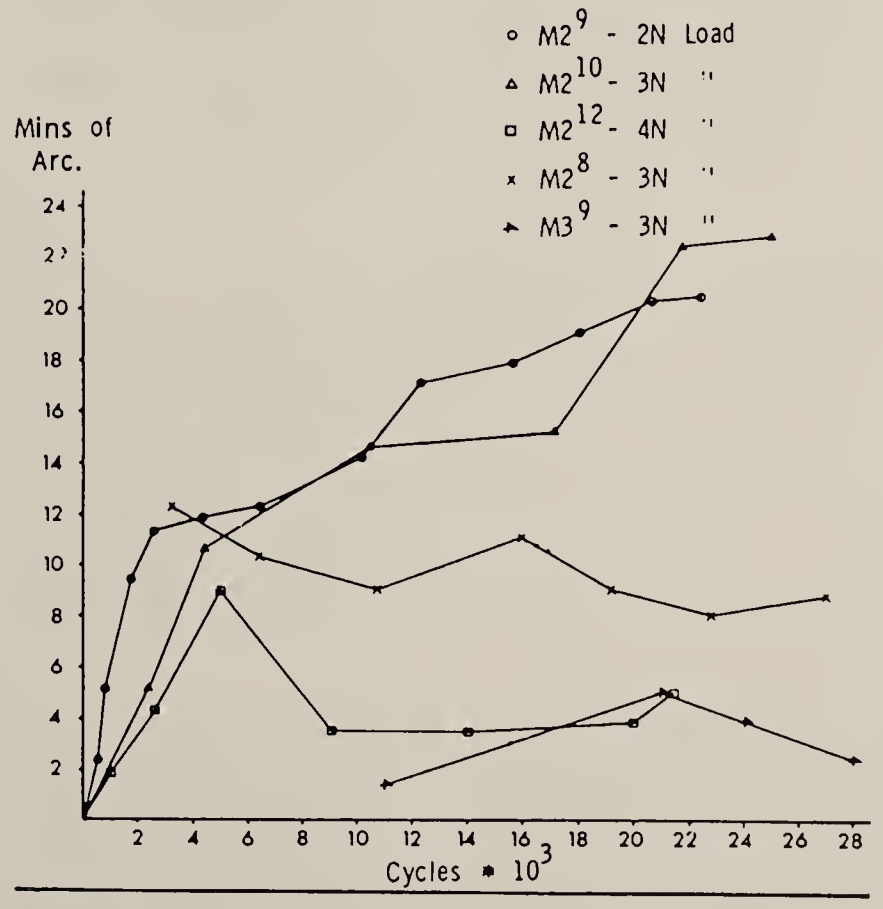
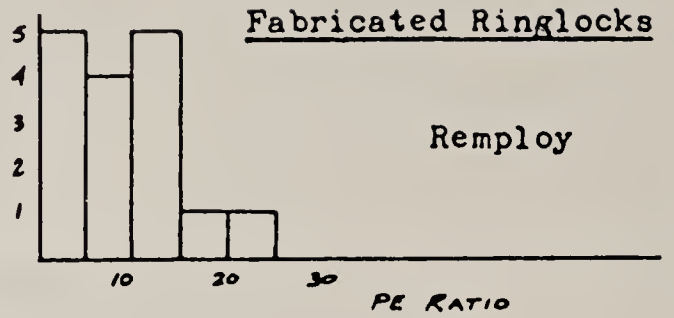
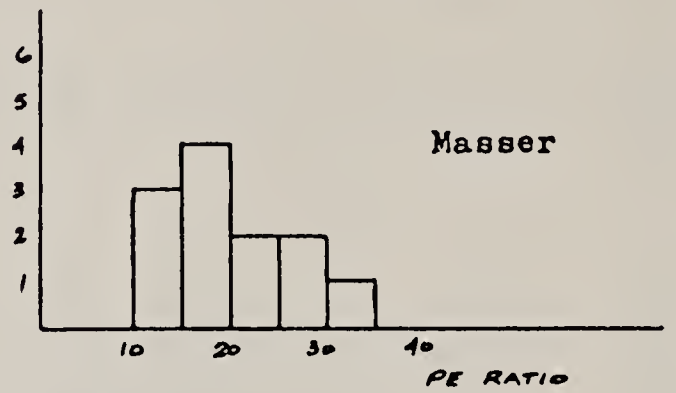
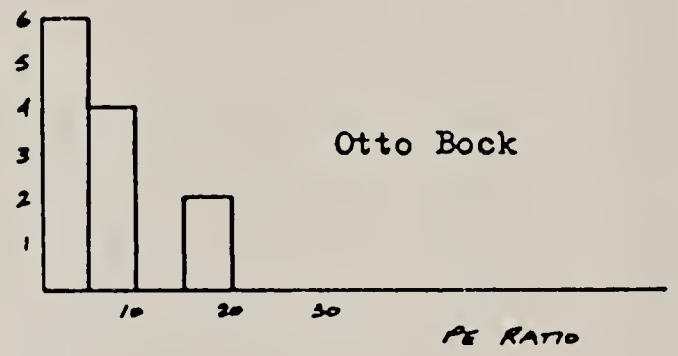


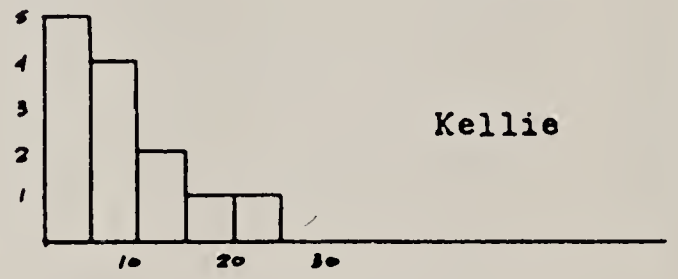
FIGURE 3
The result of a series of tests on a particular brand of ringlock: curves show no apparent connection between wear rate and applied loads, the authors point out.

Fabricated Ringlocks

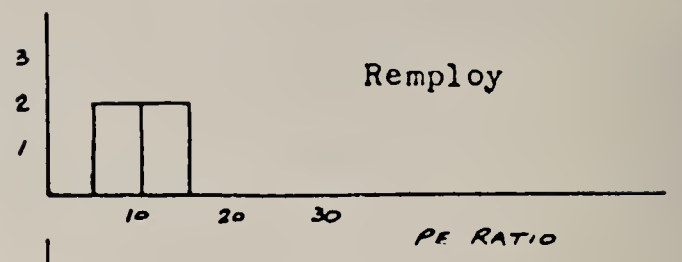


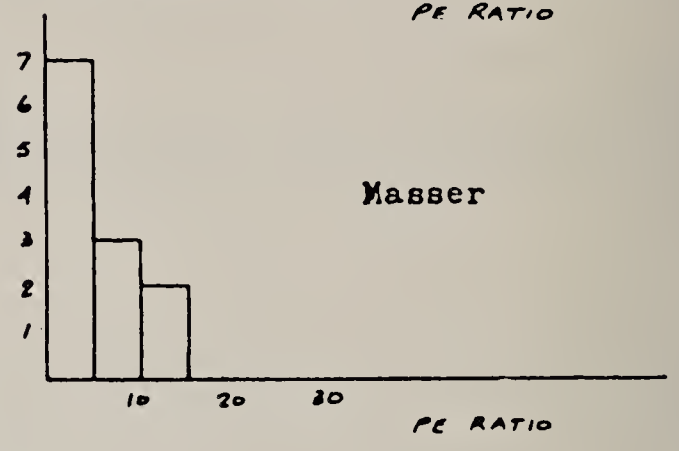


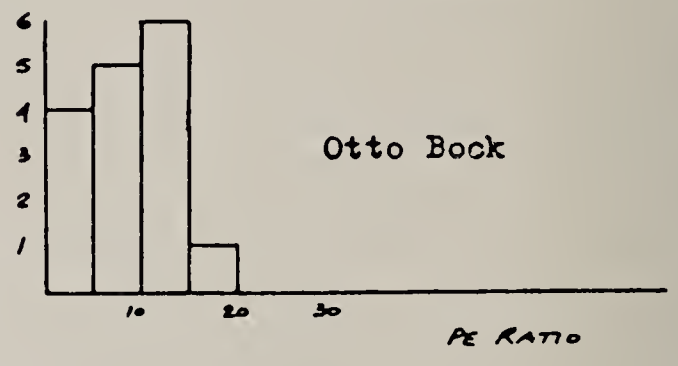




Fabricated Barlocks

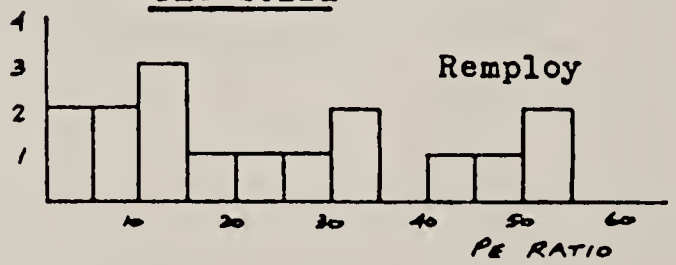


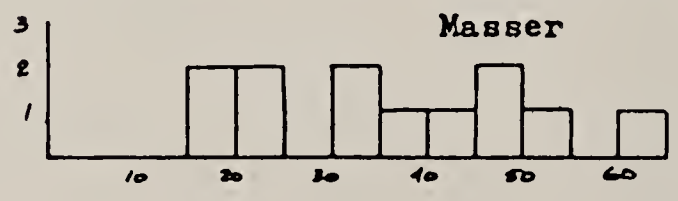


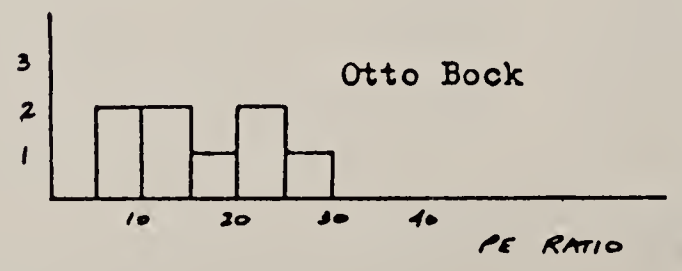


Kellie

Ringlocks machined from The Solid







Barlocks machined from The Solid

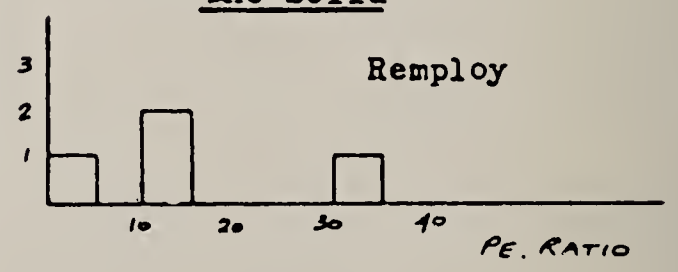


FIGURE 4
Distribution of PE ratio for four categories of knee joints. PE ratio (ratio of plastic to elastic energy) proved useful in assessing mode of failure, independent of the bending moment required to produce the failure. See text for analysis.

ings of applied load and beam rotation enable the energy absorbed during bending to be calculated, and the magnitude of elastic and plastic components provided a basis for assessing the mode of failure. Brittle failures and the release of excessive elastic energy were considered to be potentially dangerous.

In assessing the results of the bending tests, the ratio of plastic to elastic energy (PE ratio) was used. This ratio was particularly useful as it provided a good assessment of the mode of failure independent of the bending moment required to produce the failure. Ductile failures produce a high PE ratio, the opposite being true of brittle failures.

Figure 4 shows the distribution of PE ratio for four categories of knee joints. There are a number of observations to be made from this figure:

1. Those ring locks machined from the solid exhibit PE ratios frequently in excess of 40 whilst their fabricated equivalents seldom exhibit a PE ratio above 25.

2. Amongst the fabricated ring locks, the MASSER joints are superior, never exhibiting a PE ratio less than 10. This was due to correct porportioning between rivet strength and the cross section of the caliper side steels deformed plastically.

3. The bale locks are inferior to the ring locks — both machined and fabricated joints. This was due to the early shear failure of bearing pins. Invariably the side steels were far too strong and stiff in relation to the main bearing screws.

Many recommendations have been made to the British Standards Institution (BSI) and it is inappropriate to include them all here. However, certain points can be raised regarding the usefulness of the PE ratio. It is proposed that joints which exhibit PE ratios of 10 or more are considered satisfactory, those with PE ratios of 5 to 10 warrant careful attention, and joints exhibiting a PE ratio of less than 5 are to be regarded as possible candidates for redesign.

Many of the recommendations made to the BSI are concerned with the testing procedures, but many other factors are considered such as a choice of materials, standard of workmanship, assembly, and interpretation of test results ■

NZDRC (NEW ZEALAND)

FOLDING WALKING STICK

New Zealand Disabilities Resource Centre
Palmerston North Hospital Board
Private Bag
Palmerston North, New Zealand

The folding walking stick, mentioned last year, has been extensively tested by the Industrial Processing Division of the DSIR in Lower Hutt. This has resulted in valuable design information which has been used to strengthen the walking stick considerably. The device will soon be made available through the Centre.

Vehicular Mobility

Present work includes a special hand control for adapting cars with a standard gearshift. The hand control combines not only braking and acceleration functions but the clutch as well.

A Honda Civic automobile has been modified extensively and now incorporates many of the basic pieces of equipment that have been developed to date. In addition, other assessment equipment which can be temporarily installed in the client's vehicle is also under development ■

HIP AND KNEE JOINT REPLACEMENTS

STRATHCLYDE

LOWER LIMB FUNCTION FOLLOWING UNILATERAL HIP JOINT REPLACEMENT

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Previous biomechanical investigations in this department have shown significantly abnormal joint-loading patterns at both hips and knees to be present even 1 year following hip joint replacement. There was also a difference between results obtained using different prosthesis types. The current investigation is concentrated on comparing two devices: the Charnley and C.A.D. Muller total hip replacements. These

devices differ not only in design, but also in the surgical approach used, e.g., trochanteric osteotomy versus partial division of the glutei. The phasing of muscular contraction may also differ as a result.

The assessment is in two principal parts. First, biomechanical testing using the Strathclyde TV-computer system and Kistler forceplates, together with simultaneous multichannel EMG recording using a PDP 11/34 computer. Second, physiological cost of gait, based on heart rate changes at various speeds, to evaluate a physiological cost index. Some patients will also be fitted with 24-hour miniature tape recorders to monitor activity and heart rate in the domiciliary environment. Tests will be performed preoperatively and at 6, 12, and 24 months postoperatively. Initial results should be published in 1984 ■

STRATHCLYDE

EXAMINATION OF RETRIEVED IMPLANTS

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Examination of retrieved implants to determine corrosion, wear, and metallurgical condition is being undertaken. A method using a computer controlled SEM with microanalysis facilities is currently being developed. With these facilities it is hoped to be able to study segregation of constituents and impurities, as well as to obtain accurate analyses. The condition of failed implants may then be compared with those routinely removed or obtained at post-mortem. Recommendations on any necessary improvements in process control could then be offered.

Eventually, it is hoped to study the metal deposits found in the adjacent tissues. Automatic tracking techniques will prove a valuable asset ■

STRATHCLYDE

EVALUATION OF WALKING AIDS IN THE GAIT OF TOTAL HIP REPLACEMENT PATIENTS

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Walking aids are prescribed to hip arthroplasty patients to provide stability and mobility. The purpose of this study is to determine the extent to which the walking aid is used in terms of weight-bearing relief of the lower limbs. Three aids are being studied: namely; walking frame, elbow crutches, and walking sticks.

Initial experiments have used instrumented elbow crutches or walking sticks in conjunction with force platforms and three-dimensional cine film data. The loads carried by left and right aids are measured, enabling the load actions transmitted by wrist, elbow, and shoulder joints to be calculated. Force-platform measurements make it possible to analyze knee, and hip joints in a similar fashion. It is possible then to evaluate the efficacy of the particular aid being used by the patient.

It is planned to simplify the system of data collection in order to perform the measurements in the hospital wards. This approach will enable the patient's gait to be analyzed at each point in the rehabilitation procedure ■

STRATHCLYDE

EVALUATION OF INTERTROCHANTERIC FRACTURE REPAIR

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The difficulty of repairing intertrochanteric fractures to the femur in cases of osteoporosis has led to the mechanical testing of two implants commonly used at Gartnavel General Hospital, Glasgow. Strain-gaged Richards Sliding Screws have been implanted in fresh pairs of specimens and loaded under known geometrical conditions. Of each pair of bones, one screw was implanted normally while the other was implanted and subsequently surrounded with methylmethacylate bone cement in order to increase the support provided to the femoral head. The results

show interesting load sharing between bone and implant, with a significant increase in support provided by the cement. X-ray measurements have been taken to estimate the degree of osteoporosis present in the specimens.

A second series of tests is being initiated using KY nails and adopting the same experimental method. The results of both series will be compared to the clinical results of many years of surgery using these implants ■

STRATHCLYDE

EFFECTIVENESS OF OLECRANON FRACTURE REPAIR TECHNIQUES

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The use of bone screws and other techniques to effect the repair of fractures of the olecranon is being studied. Mechanical testing is underway of intramedullary screws, coronoid screws, and the posterior band-wire technique. Both human and plastic ulnae are being tested, and it is planned to model the plastic bone/implant assembly in order to validate the results obtained from the human bone tests.

The results of the mechanical analysis will be compared to the clinical experience of the three procedures performed at the Western Infirmary, Glasgow ■

STRATHCLYDE

THE BONE-CARTILAGE INTERFACE

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106 Rottenrow, Glasgow G4 ONW

Examination of surgically removed femoral heads is being made by histological, histochemical, scanning electron microscopy, and stereological techniques. The studies are aimed at determining the significance of the bone-cartilage interface in terms of its structural, mechanical, and nutritional parameters. Previous studies have indicated the possible consequences of the structural form of calcified cartilage at the interface in terms of a partial barrier to the diffusion of nutrients. Development of microprocessor-based equipment is aiding research.

Studies on pathological tissue will lead to further interpretation of the role of the bone-cartilage interface in relation to degenerative disease ■

STRATHCLYDE

MODULAR BONE REPLACEMENT PROSTHESES

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Bioengineering Unit
Wolfson Centre
106 Rottenrow, Glasgow G4 ONW

Re-section of bone, often with adjuvant chemotherapy, is now a recognized treatment of certain bone tumors. If the whole bone is not replaced, the surgeon cannot alter the length of re-section except by ordering more than one prosthesis. This is a wasteful and expensive procedure. A modular design system that can be assembled during the operation would give the surgeon flexibility and also reduce the time from diagnosis to treatment.

At present, methods of joining components are being assessed. It is hoped to produce designs for the femur, tibia, and humerus, and eventually to examine possibilities for the acetabulum and glenoid ■

LOWER LIMB GENERAL

RORRC (CANADA)

A NEW GONIOMETER FOR PHYSIOTHERAPY

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

Measurements of joint angles using conventional goniometers suffer from intertester and intratester variations, which result in errors and uncertainties when clinicians monitor a patient's progress or perform cross-patient comparisons. The major source of error appears to be in the estimation of the centre of rotation of the joint and in the placing of the goniometer's centre over this point. To overcome the problem of placement, we have designed a new goniometer that can accurately measure a joint angle without requiring an estimate of the joint's centre of rotation. This is achieved by making use of the parallelogram principle. As this double exposure shows, the pointer remains parallel to the rotating arm, even if the arm is displaced sideways. Thus, the measured value is always the angle between the two goniometer arms (in the plane of rotation). This greatly facilitates the measurement of joint angles, by giving extra freedom of movement and adjustment to the arms of the goniometer.

To use the goniometer, the clinician places the arms along the axes of the patient's limb segments. The angle between the two limb segments can then be measured accurately, regardless of the position of the centre of rotation of the joint in respect to the goniometer. If the limbs are in two different parallel planes (for example, if one limb segment is bulkier than the other as can happen in the measurement of hip angles), the parallelogram can accommodate this without any resulting error. Angles in two different intersecting planes, such as those encountered in ankle inversin/eversion, can also be measured as long as the axis of the goniometer is placed parallel to the axis of rotation (see Figure 1).

The construction of the new goniometer is very straightforward. It is a modification of commercial model, which is modified by removing part of the rotating arm and inserting a parallelogram. The parallelogram can be manufactured in any machine shop in a few hours, using readily available materials. The goniometer was designed and constructed by Rehabilitation Engineering and was evaluated by Physiotherapy ■

FIGURE 1
Use of goniometer to measure ankle inversion/eversion.

RORRC (CANADA)

A PRESSURE-MEASURING DEVICE FOR PAIN ASSESSMENT

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It is often useful to compare sensitivity to pressure at different locations on the body. Physicians generally do this by pressing on different sites with their fingers. This type of qualitative assessment can be improved upon by using a device which gives a direct reading of the applied pressure. A number of such devices, both mechanical and electromechanical, have been constructed in various centres. Our device is completely mechanical. Pressure is applied through a 1-cm² plastic disc attached to a coiled compression spring. A magnetic pointer follows the displacement of the spring and gives a reading of

applied force, in newtons. The scale on the current model reads up to 20 newtons of force. The range of force can be changed simply by changing the compression spring and making a new calibrated scale.

This pressure-measuring device is used routinely in the investigation of acute neck sprain injuries and other painful conditions ■

DERBY O&DRC (GT. BRITAIN)

SOME MECHANICAL AND RADIOGRAPHIC PROPERTIES OF BANDAGE-FORM SPLINTING MATERIALS

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There has been recently a rapid increase in the number of bandage forms of splinting materials available commercially as a substitute for plaster of paris (POP). Much work in the past has been carried out on the property of POP and some of its early competitors, but comparatively little regarding the more recent products. It was decided that six new products be compared with POP in a variety of tests designed to provide useful comparative data. The products chosen were: Scotchcast, Scotchflex, Baycast, Hexcelite, Gypsona (POP), Crystona, and Zoroc.

The tests carried out were:

1. Three and four point bending of the materials;
2. Exothermic heat production under six layers of bandage;
3. X-ray studies;
4. Fatigue studies; and
5. Compression of cylinders.

Full details of the geometry of the various test rigs and experimental conditions can be found in the following:

Pratt, D.J. et al. 1983. Some comparative properties of splintage materials. Presented at the conference "Biomechanical Measurement in Orthopaedic Practice" 14th and 15th April, Oxford, England. To be published in the conference proceedings.

Here it is more appropriate to briefly outline the results obtained from this preliminary study, bearing in mind that it is still continuing.

Of all the splinting applications of these new materials the requirements of the walking cast are the most demanding. An orthopaedic walking cast should have the following criteria satisfied if it is to be successful: (i) high strength-to-weight ratio, (ii) water resistance, (iii) ease of application, (iv) high fatigue life, (v) high radiolucency, and (vi) cost-effectiveness. If all the products are examined in the light of these criteria then the following conclusions are possible:

1. The highest strength-to-weight ratio, in terms of three and four point bending and compression of cylinders, is found in Scotchcast.
2. All the materials, except Gypsona and Zoroc, are water resistant.
3. Ease of application is a subjective property but Gypsona, Zoroc, and Crystona seem to be the easiest, perhaps due to their similar application technique. The least popular product on this point was Baycast.
4. Both Scotchcast and Scotchflex have high fatigue lives, much higher than the POP like materials with Baycast in the middle.
5. Baycast has by far the highest radiolucency with Scotchcast the highest of the remaining products. It is unlikely, however, that any of the products would cause difficulty with their radiolucency.
6. The cost effectiveness of products such as these is very difficult to assess. If, by using a product, the time spent on cast repairing and the time spent in hospital can both be reduced, then a net saving should result. However, due to the way in which the accounting is performed within the National Health Service, this is not seen to be the case. It still seems to be the case of finding the cheapest product to do the job ■

LOWER LIMB PROSTHETICS
GAIT ANALYSIS

RORRC (CANADA)

GAIT LABORATORY

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The gait laboratory at the Royal Ottawa Regional Rehabilitation Centre is located in Rehabilitation Engineering. The purpose of the gait laboratory is, primarily, to provide a clinical gait analysis service to clinicians in the Centre and, secondarily, to per-

form research. The emphasis on clinical gait analysis necessitated the streamlining of measurement and reporting techniques so that a large number of patients could be seen. The gait laboratory and the analysis procedures will be discussed in the following paragraphs.

The gait laboratory contains a walkway 10 metres long and 5 metres wide. A force plate (A.M.T.I.) is concealed in the centre of the walkway, for the measurement of three-dimensional forces and moments during a step. The force plate is embedded in the concrete floor, thus eliminating the necessity of using a raised platform. Two video cameras obtain frontal and sagittal views of the patient during gait. Two infra-red beams measure the instants when the patient crosses two specific locations on the walkway, giving the appropriate timing and velocity data.

The patient is instrumented with Lamoreux-type goniometers which measure angles of hip, knee, and ankle, bilaterally, in the sagittal plane. Foot switches record the times of heel contact, foot flat, heel off, and toe off. In addition, up to six channels of EMG can be measured.

Data processing — All of the data collected in the gait laboratory are fed to a PDP 11/34 computer with a 16-channel analog-to-digital converter. Immediate plots can be made of goniometer data, foot switch data, EMG data, and force plate data, with time as the independent variable. Off-line processing, done immediately after the gait analysis, produces the following additional data:

1. Goniometer and EMG data with percent stride as the independent variable.
2. A comparison of the patient's data and normal (averaged) data, on the same hard copy, with percent stride as the independent variable.
3. Temporal/spatial parameters: cadence, velocity, step length, stride length, stance time, swing time, double support time, and angular range of motion.

The step base is measured from the video record using a scale on the floor of the walkway.

Procedures for clinical gait analysis — An initial videotaping is made of the patient's ambulation, prior to applying the instrumentation. The patient is then instrumented with six electrogoniometers for bilateral assessment of hip, knee, and ankle joint angles. Foot switches are fixed to the soles of each shoe. Up to six pairs of EMG electrodes can be placed on the patient's leg muscles. When required, the force plate can be used to measure the three-dimensional forces and moments of stepping. Generally, two runs are performed for each specific evaluation to ensure consistency of the recordings.

The written reporting procedures are in two stages:

1. Initially, a brief documentation of the results is made using a "quick gait analysis" form. This form was designed to provide rapid feedback (within 2 days) to the patient's attending clinician, in order to plan further treatment.
2. A more comprehensive interpretation of the results is made on a form entitled: "report on gait analysis". This latter report is then placed on the patient's medical chart.

The Gait Laboratory is operated by Rehabilitation Engineering and Physiotherapy staff, in association with physiatrists and other clinicians ■

RORRC (CANADA)

JOINT POSITION TRAINER

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This device was designed for use in physiotherapy to train stroke patients to achieve appropriate movement at the knee while walking. The knee angle is measured using a Lamoreaux-type electrogoniometer. Two thresholds can be selected, one for knee extension and the other for knee flexion. Reaching or exceeding the extension threshold will result in a high-pitched audio tone. Reaching or exceeding the flexion threshold will result in a low-pitched tone. No tone sounds if the knee angle is in between the two thresholds. As the patient progresses, the thresholds can be set wider apart until the desired range of motion is obtained.

The joint position trainer can be used with limbs other than the knee and for patients other than stroke patients ■

LOWER LIMB PROSTHETICS
MISCELLANEOUS

IMA (ARGENTINA)

BIOMECHANICS RESEARCH AND DEVELOPMENT AT IMA

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It is one of the main goals of the present report to describe the IMA crutch which attemps to "accompany" the human body in a more active manner by providing:

1. Deformable underarm support;
2. Deformable handgrip;
3. Full contact between crutch tip and ground for any position of the crutch by means of a self-aligning bearing (the possibility of sliding accidents is then greatly reduced);
4. A geometric change when modifying the position from standing to sitting and viceversa.

On the other hand, it has been possible to introduce certain basic modifications on forearm crutches and canes and special care has been taken in the design of walking-aids for handicapped children.

The authors have developed these elements in accordance with present and future needs, and technical and social possibilities of a developing country like Argentina. With regards to research and development in the rehabilitation engineering field in South America it may be worthwhile to recall that data presented at the Second World Congress of ISPO in 1977 showed all of South America as having no rehabilitation engineering R&D centers at all (the total number in the world was put at 561, of which North America had 267, Europe 233, Africa 4, Asia 36, and Australia 21).

Retractile, anti-shock, non-sliding "IMA" crutches and further developments — Since 1981 a special program dealing with elements for disabled children is in progress at the "Instituto". These elements are: underarm crutches, forearm crutches, canes, etc.

The fact that in all cases the ratio weight/resistance has been minimized must be emphasized. The metal used has been standard aluminum in practically all situations. Obviously, the weight/resistance parameter may be improved considerably if alloys of better quality are used.

Description of the "IMA" crutches — This orthotic device presents several attractive features from an overall mechanics-functional viewpoint.

1. It is retractile (adaptable to several lengths, easy to transport when not in use, etc.);
2. The armpit support and the crutch handle are flexible, internally damped and anatomic in shape (acts like a shock-absorber under the impact induced even in normal walking);
3. The "ground structural element" which consists in the tip which is mounted on a self-aligning spherical bearing (the possibility of a sliding accident is greatly decreased by means of this device), and
4. When the person sits, he adapts the full length of the crutches to a convenient length. A system of springs is then compressed, but when the person stands up, the springs recover the initial length.

Angle-adjustable forearm "IMA" crutches — Stated in terms of engineering design requirements, the improvements obtained with the "IMA" forearm crutches are:

1. Arm supports: deformable and of conical shape;
2. Angle-adjustable handgrips and cuffs in order to accommodate to the disabled actual needs;
3. Crutch handle with deformable upper portion; and
4. Tip mounted on a self-aligning spherical bearing.

Each crutch weighs 1.00 Kg.

"IMA" Canes — Useful discussions with physicians and disabled persons lead to the idea of developing a new type of cane with the following characteristics:

1. Handle with deformable upper portion;
2. Continuously varying length (it can accommodate to practically any person: short or small);
3. Non-sliding tip (mounted on a self-aligning spherical bearing).

It is important to emphasize the fact that the "IMA" cane weighs 0.375 kg.

Elements developed for disabled children — Following the criteria previously established for orthotic devices for adults, underarm crutches, forearm crutches, and canes were developed for disabled children.

Each forearm crutch weighs 300 g and the length may be varied from 40 to 65 cm, while this length variation goes from 65 to 95 cm in the case of underarm crutches.

A rather unique concept has been developed in the design and construction of the child crutch. It was developed for the special situation of a 6-year-old child who uses crutches when performing activities

outside his home. However, when walking inside his house, he feels safe walking with a cane. By pressing a button and applying compression the disabled child can convert the crutch into a cane.

A "karting" type vehicle for disabled children was developed at the Instituto de Mecanica Aplicada. Its conception is based, fundamentally, in the design of the "Caster Cart" developed at the Ontario Crippled Children's Centre (Toronto-Canada).

A multipurpose walker, child and junior size, which has been developed at IMA possesses the following features:

1. As a deambulator, it offers parallel bars, crutches, and a balance ring.
2. For transportation purpose, it serves as a transport chair, and
3. For feeding and schooling purposes, it provides a removable tray and a seat.

The material is aluminum; total weight including all accessories is 22 lb (this fact constitutes a definite advantage, considering the much larger weight of foreign walkers known in Argentina). Since the dimensions can be adjusted easily, it can be used for ages varying from 6-year-old children to 14-year-old teenagers, according to the experience obtained at IMA ■

UPPER LIMB GENERAL

RORRC (CANADA)

EMG BIOFEEDBACK

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A two-channel EMG biofeedback system was designed and constructed by Rehabilitation Engineering for use by therapists in patient re-education and for the performance of research. This biofeedback system can measure the full frequency spectrum of the EMG signal. Most of the EMG frequency spectrum lies in the range of 20 to 100 Hz, a range which is eliminated in many commercial EMG biofeedback systems. The fact that changes in EMG due to neuromuscular regeneration, or due to muscle fatigue, occur in lower half of the spectrum further emphasizes the importance of providing biofeedback in this range.

Our EMG biofeedback system consists of the following:

1. A two-channel TECA EMG system with AA6 Mk III amplifiers.
2. A two-channel oscilloscope.
3. A two-channel high-fidelity audio system.
4. Two digital displays showing integrated full-wave rectified EMG with integration periods variable from 1 second to 60 seconds.

The TECA amplifiers contain remote preamplifiers which are placed close to the patient, thus enabling short electrode leads to be used. The oscilloscope is required because the wide bandwidth used increases the risk of picking up interference due to power lines, movement artifact, etc. The oscilloscope can be used to distinguish between EMG signals and interference signals. If interference signals are observed, appropriate steps can be taken to eliminate them. The high-fidelity audio system is used for direct feedback of the raw EMG signals. It is also useful in detecting certain types of high frequency noise, such as that caused by electrode leads rubbing on the skin.

The EMG biofeedback unit is used in the centre by physiotherapists, occupational therapists, and psychologists, for muscle re-education and for relaxation therapy ■

RORRC (CANADA)

A WRIST GONIOMETER

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Physiotherapists often need accurate measures of wrist flexion and extension when training patients with peripheral neuropathies or with stroke. The goniometer uses a Lamoreux-type parallelogram with specially designed support to prevent it from collapsing. Connected to a pen recorder, it accurately displays wrist angle and range of motion.

Other applications of the goniometer include audio and visual biofeedback for training wrist control and for increasing wrist range of motion.

The goniometer can be adapted for other joints, such as the elbow, by changing the attachments to fit the different limbs. To ensure accurate measurements, care must be taken that the goniometer is in the plane of movement ■

STRATHCLYDE

A STUDY OF DYNAMIC FUNCTION IN THE RHEUMATOID HAND

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Rheumatoid arthritis is a common disease, affecting 2 percent of the population in Britain. One of the areas frequently affected is the small joints of the hand, where a gradual deterioration of function takes place. The development of the deformities is not clearly understood, and it is not possible to forecast the pattern of deformity by methods of assessment currently in use. It is believed that a more thorough knowledge of mechanical factors involved in the movements of the rheumatoid hand during the early stages of the disease will allow for better understanding of the factors leading to the development of deformities in the later stages. This will allow improved treatment incorporating the provision of orthoses, technical aids, and advice on methods of joint protection/preservation. In this project, the coordinated joint motions and loads developed during function of the rheumatoid hand are being measured and studied. An evaluation of the treatment and advice relating to the theories of joint preservation/protection is being carried out ■

STRATHCLYDE

UPPER LIMB LOAD ACTIONS DURING CERTAIN ACTIVITIES IN MEN'S OLYMPIC GYMNASTICS

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It is the aim of this project to determine, in mechanical terms, the interactive movement patterns and the corresponding forces during the performance of skills within the skill classification of 'kip actions.' This includes assessment of the timing and direction of application of forces by the gymnast in relation to instantaneous positions during the performance of skills. Once this has been determined for individual skills, it will be possible to establish biomechanical principles for the classification of all skills in order of difficulty within the category; hence, providing more effective and safer coaching schedules.

The practical experimental work in the research involves the acquisition of cine film and force transducer data during performance of 'kip actions' on the horizontal bar, parallel bars, rings, and in floor exercise. In order for this to be possible, it has been necessary to install the gymnastic apparatus in the Biomechanics Laboratory at the University of Strathclyde.

Strain-gage force transducers have been designed to form an integral part of the parallel bars and ring apparatus. Strain gages have been applied directly to the horizontal steel cross bar, and forces were measured during floor exercise skills, using two force plates installed in the laboratory.

The performances were filmed by two cine cameras in order to obtain three-dimensional spacial information relating to the movements. Computer programs manipulate the film and force-transducer data to aid in the final analysis of the resultant forces transmitted between the segments of the performer's limbs together with the moments ■

Spinal Cord Injury R & D

ELECTRICAL STIMULATION AND GAIT ANALYSIS

RORRC (CANADA)

AN EMG PROBE ELECTRODE

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The process of regeneration following nerve injury can result in very isolated regions of EMG activity occurring in limb muscles. These small regions of activity can often be missed in conventional electromyography using needle electrodes, and in standard biofeedback using surface electrodes with normal placement. A probe electrode (Fig. 1) has been designed that can be moved over the surface of the muscle area to find regions of activity which might otherwise be missed. When activity is found, the locations are marked and normal adhesive surface electrodes are applied.

The probe electrode's contact points are tipped with saline pads, to make good contact. The spacing of the pads can be varied, along with their orientation with respect to the handle. A long handle is used to minimize interference pick-up from the person holding it. Even with all possible precautions taken, a considerable amount of interference (power-line interference, movement artifact, etc.) is usually picked up by the electrode. Thus, an oscilloscope display is essential so that EMG signal can be distinguished from artifact.

This probe electrode has successfully found EMG activity that was missed in standard electromyography. Later clinical electromyographic examinations confirmed the findings of the probe electrode ■

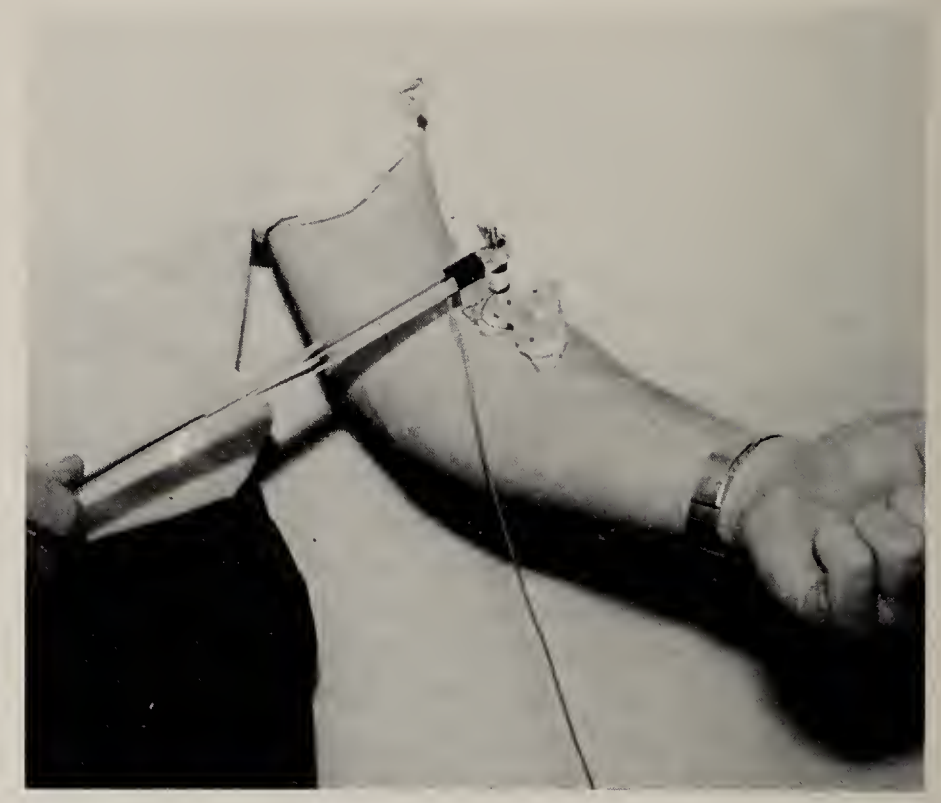

FIGURE 1
EMG probe electrode.

MOBILITY AIDS WHEELCHAIRS

NZDRC (NEW ZEALAND)

INDEPENDENT MOBILITY FOR CHILDREN

New Zealand Disabilities Resource Centre
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The SEDO wheelchair, a children's wheelchair embodying three chairs in one, has been extensively redesigned as a result of the field-testing described in last year's review. Strong interest has been shown by several wheelchair companies in this wheelchair.

The first prototype of the "Go Cart", a mobility aid for very young disabled children, has currently been tested with one child. Testing on a wider scale is planned.

The SEDO wheelchair has been specially adapted for amilic children. The modular nature of the wheelchair lends itself to this sort of adaptation. The seat height can be adjusted by the child to suit various work/play surfaces. It can be lowered to ground level to promote independent transfer.

The Department of Industrial Management and Engineering at Massey University have used their advanced technical knowledge in cooperation with the Centre to develop a microprocessor-based wheelchair controller. Such a device will provide greater flexibility in adapting the controlling mechanism of an electric wheelchair to suit the specific needs of the client. It should also assist measurably with the safety of such devices because of the device's ability to shut down under fault conditions ■

MOBILITY AIDS
WHEELCHAIR ACCESSORIES

RORRC (CANADA)

MODIFICATIONS TO WHEELCHAIR FOR A HIGH-LEVEL QUADRIPLEGIC

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A quadriplegic with a C1-C2 lesion required special adaptations to his electric wheelchair. The original wheelchair was a fully-reclining model built by Everest and Jennings. It came with a sip and puff control manufactured by Medical Equipment Distributors Inc. of Maywood, Illinois, The following modifications were performed by Rehabilitation Engineering in association with Occupational Therapy:

1. An electrically operated horn was placed in series with the emergency stop control. This enabled the patient either to activate the horn alone with a small push, or both horn and emergency stop with a longer push.
2. A bumper was attached to the footrests to protect the subject in the event of an accidental collision. Such collisions occurred quite frequently in the beginning, due to the difficulty in operating the wheelchair with a single sip and puff control.
3. Circuitry was installed so that the reclining mechanism could be operated by the user using a second sip and puff switch.
4. A gravity-operated goniometer was installed on the wheelchair to give a continuous indication of the reclining angle.
5. Modifications were made to the back of the wheelchair to prevent dangerous levels of vibration occurring while traveling on rough ground.

This wheelchair, with its adaptations, is operating very successfully and the modifications are important contributing factors to this person's rehabilitation ■

RORRC (CANADA)

A WHEELCHAIR BUMPER

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Conventional wheelchairs, whether manually or electrically propelled, leave the feet of the users exposed and quite vulnerable. Thus, severe injury could occur to the feet in a collision. This danger is especially severe with quadriplegic persons since, with no movement of either hands or feet, they may be unable to protect themselves in the event of a collision.

A bumper was designed which can be fitted on almost any wheelchair and which will protect the user's feet in a collision. Furthermore, because of its design, the bumper is very useful in some wheelchair sports by providing a means for pushing a ball. Since the danger of injury is greatest during competitive sports, the bumper is especially valuable in those circumstances.

The shape of the bumper is such that it will envelop the feet as much as possible without restricting transfers to and from the wheelchair. To attach the bumper to a wheelchair, it is simply necessary to remove the small rubber tips from the footrests. The bumper then slides on, and is fixed to the wheelchair by the same metal screws that are used to hold the rubber tips. The special attachment system enables the bumper to be adjusted for different wheelchair widths and different angles of the footrests. Since the bumper is 6 inches high, a 4-inch height difference between two bumpers will still allow protection in the event of a head-on collision. (For very high footrests, small blocks can be made to lower the bumper to an acceptable height.)

The bumper is used regularly by high-level quadriplegic persons who, because of difficulty in control-

ling their wheelchairs, experience frequent accidental collisions. In addition, the bumper is used regularly by persons playing a game called "pushball." The game was originated by Leisure and Recreation, for whom the bumper was first designed. In this game the bumper is used to control the ball; at the same time, it provides protection to the feet.

The bumper is made of vacuum formed high-density polyethylene, with ancillary metal supporting parts. The construction is relatively simple, and with the exception of the vacuum-formed part, can be manufactured in any mechanical shop ■

RORRC (CANADA)

ADJUSTABLE WEIGHTS TO PREVENT WHEELCHAIR TIPPING

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Lower-extremity amputees with high-level bilateral amputations frequently use wheelchairs for mobility. For these people, the centre of gravity is high and quite far back on the wheelchair. Thus, there is a constant danger of the wheelchair tipping backwards. Special adapters for amputee wheelchairs solve the problem in most of the cases; but for many high-level amputees the danger remains, particularly when climbing ramps.

Adjustable sliding weights have been designed which enable the centre of gravity of the wheelchair, with its user, to be adjusted for optimum safety. Each weight is 7 lb and can slide on a 14-inch rod. The wheelchair can be collapsed and stored without the removal of the weights. Thus, it is suitable for wheelchairs that must be transported by car ■

DERBY O&DRC (GT. BRITAIN)

THE EXAMINATION AND COMPARISON OF SEATING AND POSTURAL SUPPORT SYSTEM AVAILABLE IN 1980, TO DEFINE CRITERIA FOR THEIR PRESCRIPTION

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In 1979 the Orthotics and Disability Research Centre, Derbyshire Royal Infirmary, reported on the results of assessment of three different types of moulded body support. During that study, techniques have been developed to record and analyse clinical and functional data on the patients involved, and these have made it possible to assess the benefits of the three systems being considered, which are custom moulded thermoplastic shell, moulded external corset-type support, and sunflower custom cushion.

By the time that report was submitted, a range of postural supports had become available and a number of centres were producing their own form of special trunk-supporting devices. It was therefore proposed that the study should be carried out to define prescription criteria for the available range of commercial and other types of trunk support. The need for the provision of postural support to patients unable to support themselves in wheelchairs and geriatric chairs is well known. As the awareness of the need to solve seating problems has increased, so there has been a corresponding increase in the number of commercially available devices. These include evacuated beanbag-type supports, wheelchair bolt-on supports, and a number of specially designed rigid supports. Despite the number of systems that were and are available, there is little firm data on which to base prescription decisions. In view of this, the Orthotics and Disability Research Centre at Derbyshire Royal Infirmary obtained a grant from the Department of Health and Social Security to carry out this 3-year project.

The aims of this project were:

1. To produce a catalogue of the available seating systems and postural supports available at the time and to examine these, grouping each item into principal types according to their design, construction, and function.
2. To obtain samples of 25 adults and 25 children with severe seating, postural, and trunk-support problems having as wide a range of diagnosis and age as possible.
3. To identify the prescription criteria for each

type of seat or group of seats through each patient trying each type of seat and taking into account as many physical and functional aspects of each seat as possible.

The final report for this particular project has only recently been submitted to the DHSS and we are unable to provide full details of the results of this particular project yet. However, full details of this should be released ready for the next progress report and will certainly appear in various publications ■

NZDRC (NEW ZEALAND)

WHEELCHAIR ADAPTATIONS

New Zealand Disabilities Resource Centre
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Palmerston North, New Zealand

A new project under development is a Caster-Wheel Lock. This device is currently being developed with the Otara Spinal Unit. It is used to help stabilize a wheelchair by preventing the front casters from swiveling during lateral transfers from the wheelchair to another seat.

Special Seating and Support

A number of specialized supportive devices have developed this year, including (i) prone stander, (ii) standing frame, (iii) canvas slung seat, (iv) mountain chair, (v) child's car seat, and (vi) a special feeding chair aimed at institutional use.

A solid seating project is designed to replace the plywood, foam, and vinyl custom-made seats habitually used for people with cerebral palsy and muscular dystrophy. Using a modular approach, the solid seating system will be flexible enough to accommodate for the needs of such individuals. Because of its flexibility it will permit changes in posture on a daily short-term basis and accommodate for physical growth in children in the longer term. Such a system should prove more comfortable, functional, and practical from the user's point of view than the relatively fixed form of custom upholstered seating. The system will also be designed to interchange with the SEDO wheelchair and the "Go Cart" ■

MOBILITY AIDS
DECUBITUS ULCERS
CUSHIONS

STRATHCLYDE

PROVISION OF WHEELCHAIR CUSHIONS FOR PATIENTS AT RISK OF DEVELOPING PRESSURE SORES

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Helen Hayes Hospital
West Haverstraw, N.Y.

Wheelchair cushions consisting of flexible polyurethane foam supported on a more rigid polyethelyne foam are provided for paraplegic patients and others who are at special risk of developing pressure sores. Interface pressure measurements are made; and where the pressures at the ischial tuberosities are considered excessively high, a simple cut-out is provided and modified until acceptable measures are obtained.

A key element of the program is the regular follow-up of the patients, and it is becoming clearer that flexible foam cushions have a limited useful life of 9 to 15 months for the majority of patients ■

RORRC (CANADA)

INFRARED THERMOGRAPHY

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

An Agatronix 780 infrared thermography system is operated for the Centre by Rehabilitation Engineering. This equipment is used for the following purposes:

1. For spinal cord injured patients as part of a program to prevent decubitus ulcers. Reactive hyperemia, often an indicator of the future onset of a decubitus ulcer, can be monitored quite easily with thermography.
2. The monitoring of temperature changes associated with pain.
3. The monitoring of temperature changes associated with nerve injury.
4. The monitoring of global temperature changes during standard temperature biofeedback. Standard temperature biofeedback uses very small thermistors on appropriate limb segments. The patients are asked to increase or decrease the temperature, as indicated by the thermistor, depending on the type of feedback being performed. It is of interest to us to determine what temperature changes are occurring in the areas surrounding the thermistor ■

ADL AND RECREATION

RORRC (CANADA)

OPERATION OF VIDEO GAMES BY HIGH-LEVEL QUADRIPLEGICS

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

High-level quadriplegics are often unable to operate the joystick used in video games. We performed modifications to enable a sip-and-puff switch to be used instead of a single joystick. A second sip-and-puff switch is used to reset the game. Since many video games involve the activation of a "firing" command, a pressure switch is placed at a suitable site on the body (such as behind the head) enabling the user to perform that function.

A single-stage sip-and-puff switch can be used for games involving only left-right or up-down control. For games involving both control directions, a two-stage sip-and-puff switch is necessary. (The two stages are achieved by two levels of sip and two levels of puff).

Quadriplegics, even at the C1-C2 level, have achieved quite a high degree of expertise in the playing of video games using this system ■

RORRC (CANADA)

A KNIFE HOLDER

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

A knife holder was designed and built for a quadriplegic person who lacked adequate grip strength to hold eating utensils. This holder, which is made of phenolic, is fixed by leather and velcro bands at the hand and wrist. The device can be applied easily with the other hand.

This knife holder is very useful as an eating aid. Other utensils, such as forks or spoons, can be fitted to a similar harness ■

RORRC (CANADA)

LEATHER-WORK TOOL HOLDER

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

This device was designed for persons who have only one usable arm and who wish to do leather work involving the use of metal punches. The tool holder can hold the punch against the leather, freeing the hand to operate the hammer. To use the holder, the punch is slid into the metal block. The knob is tightened, to hold the punch firmly. The punch is placed against the leather and then hammered.

The leather tool holder was built for Leisure and Recreation for a leathercraft course. Users include unilateral amputees, hemiplegics, etc. ■

STRATHCLYDE

LOWER LIMB LOADINGS DURING SELECTED SOMERSAULT ACTIVITIES

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Bioengineering Unit
Wolfson Centre
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The purpose of the present investigation was to describe the function of muscle groups about the hip, knee, and ankle joints during performance of a standing back-somersault. International gymnasts acted as subjects, and each subject performed two trials which were recorded on 16-mm film. Ground reaction force records were also obtained during each trial, and the film and force records were synchronized for the purpose of analysis. Moments of force about the hip, knee, and ankle joint during take-off were calculated for all trials.

The results show that hip moment is dominant throughout the whole of the take-off period (dip and propulsion phases) and contributes between 44 percent and 76 percent to the total support moment (Ms). The moment about the ankle contributes between 20 percent and 40 percent to the Ms; whereas, the moment about the knee (3 percent to 30 percent of Ms) shows a single peak that occurs close to the point of zero vertical velocity at the end of the dip phase. It would appear that the hip and knee extensors are largely responsible for breaking the fall of the whole-body c. of g. during the dip phase (eccentric contractions), while the hip extensors in combination with the plantar flexors of the ankle are largely responsible for generating upward velocity of the whole body c. of g. during the propulsion phase (concentric contractions).

Other activities will be tested, and it is envisaged that the information will provide coaches with a greater understanding of control of the lower limb, giving reduction in injury frequency ■

RORRC (CANADA)

GOLF AID

Royal Ottowa Regional Rehabilitation Centre
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We were asked by Leisure and Recreation to produce a golf club attachment for indoor putting from the sitting position. The golf aid which we constructed is shown in Figure 1. The attachment grips the golf club firmly and holds it away from the user's knees. Users of this attachment have achieved a good level of skill in putting ■

FIGURE 1
Golf club attachment allows indoor putting from a sitting position.

TREATMENT AND TRAINING

RORRC (CANADA)

TILT-SENSITIVE BUZZER

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario K1H 8M2, Canada

A buzzer was designed to train patients to correct postural deficits. It contains a mercury switch with a buzzer circuit, which is activated when a specific angle is exceeded. The angle at which the buzzer sounds is fully adjustable and is determined by its placement on the patient. The package is in the shape of a disc, 3.5 cm in diameter by 1 cm deep. The small size enables it to be placed under the clothing, making it almost invisible.

The buzzer is used to correct postural deficits in a wide variety of patients, including those with Parkinson's disease and those with torticollis. It is easy to use and quite inexpensive to construct ■

RORRC (CANADA)

A MOUTH SWITCH TO TRAIN FOR NOSE BREATHING

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

A mouth switch was designed to train a patient to breathe through the nose. This patient had cerebral palsy, accompanied by mild mental retardation. He had a dental malocclusion which required a jaw resection. A complicating factor was that he was a mouth breather. It was feared that he would suffocate in his sleep while his jaw was wired shut as part of the post-operative procedure.

The mouth switch was used to give biofeedback to the patient prior to the operation. During the biofeedback sessions, a loud tone sounded if the mouth was opened, even slightly. During 2 months of biofeedback performed by Communication Disorders (who originally requested this device), the patient achieved nose breathing to a degree that the surgery could be undertaken.

The mouth switch can be made in different sizes. It has a vinyl cover, making it watertight. Thus it is safe and washable. A variety of controlled outputs can be used with the switch, including lights, radio, etc ■

DIAGNOSTICS AND INFORMATION

STRATHCLYDE

PRESSURE SORE PREVALENCE

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Pressure sore prevalence was assessed in large groups of patients within Greater Glasgow and (Scottish) Boarders Health Board Areas. The prevalence of lesions that could be unequivocally identified as pressure sores was in excess of 8 percent in both areas. Elderly patients formed the majority of those with sores, although they represented a minority of the patient survey population. Patients with neurologic damage also had a high sore prevalence.

The deleterious influence of immobility and incontinence was demonstrated by data ■

STRATHCLYDE

THE MEASUREMENT OF THE MOBILITY OF SUBJECTS IN BED

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The movements made by normal subjects in hospital beds have been measured by supporting the bed legs on load cells. Initial studies, made using an entirely analog system, show that normal subjects were highly mobile, and the durations for which pressures acted were considerably shorter than the pressure histories produced by two-hourly turning of immobile patients.

More recent studies on elderly patients (Dr. R. Kennedy, Stobhill Hospital, Glasgow) have employed a digital system to detect and measure body movements. The results indicate that the majority of patients assessed as being at risk of developing pressure sores could be detected using mobility parameters obtained after 2 nights of monitoring subsequent to admission to the hospital ■

STRATHCLYDE

EVALUATION OF INTERFACE CONDITIONS ON HOSPITAL MATTRESSES

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Measurements have been made of the interface pressures and temperatures produced by normal subjects and paraplegic patients lying on a variety of foam and interior sprung mattresses. It was shown that significantly different pressures could be produced by lying on different mattresses and that the fitting of an inextensible mattress cover elevated the interface pressures.

Long-term temperature measurements showed that abnormally elevated temperatures were present at skin-support surface-contact areas ■

NZDRC (NEW ZEALAND)

COMMUNICATION ASSESSMENT AID FOR CEREBRAL PALSIED CHILDREN

New Zealand Disabilities Resource Centre
Palmerston North Hospital Board
Private Bag
Palmerston North, New Zealand

The Centre is developing a relatively simple scanning communication aid to help therapists and other professionals make a preliminary assessment of the abilities of such children. This work is being carried out by an electrical engineer sponsored through a fellowship provided by the Auckland Industrial Development Division of the DSIR ■

RORRC (CANADA)

HEAD-ROTATION GONIOMETER

Royal Ottawa Regional Rehabilitation Centre
505 Smyth Rd., Ottawa, Ontario, K1H 8M2, Canada

Physiotherapy training, following injuries such as whiplash, often requires the measurement of range of head rotation. This measurement is commonly done using a magnetic compass attached to the head. However, patients who cannot hold the head fully upright often cause the compass to get stuck, thereby giving a false reading. A standard car compass was modified by adding gimbals which compensate for non-rotational movements of the head. The goniometer is mounted on a hockey helmet to facilitate placement on the head. A locking thumbscrew enables the therapist to zero the compass for easy reading.

This device is used routinely by physiatrists and physiotherapists as part of an Acute Neck Sprain Study which is in progress at this centre ■

Sensory Aids R&D

BLINDNESS AND VISUAL IMPAIRMENT

AIST (JAPAN)

BOOK-READER FOR THE BLIND

Agency of Industrial Science and Technology
Ministry of International Trade and Industry
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Tokyo, Japan

The Agency of Industrial Science and Technology (AIST) of the Ministry of International Trade and Industry has a research contract with Nippon Electric and Anritsu Electric to develop a book-reader for the blind, a system to turn pages and read print from a few Japanese type fonts. Industrial Products Research Institute (IPRI) of AIST is developing a book-reader for multi-fonts, but without an automatic paging system. Nippon Telegram and Telephone Corporation is developing an automatic paging robot and reading machine separately.

IPRI's new reading machine system for the blind consists of three units: (i) a reading unit with optical scanner, (ii) a recognition unit for multi-font Chinese characters, and (iii) a speech-synthesis unit to convert recognized characters into spoken Japanese. Experimental studies are being done to obtain insight into a method for recognizing multi-font characters with a single dictionary, and for generating a synthetic voice.

The reading machine contains a small TV camera that picks up the characters in a sentence, breaks down the characters into small dots, and feeds the data into a computer. The computer is equipped with a memory that serves as a dictionary containing 1,059 printed characters — the 881 kanji (ideographs) most frequently used (those required to be learned in school), the hiragana and katakana phonetic symbols, and punctuation marks. Printed Japanese is a mixture of kanji and kana, so a larger memory capacity is required for the recognition of Japanese text than for English text. This drawback has been overcome with the development of high-density integrated circuits that produce small-sized memories with large capacities. Characters are read and identified through the extraction of outline features and detail matching of line distribution patterns, and converted into synthesized voice ■

UC (NEW ZEALAND)

ENHANCED SPATIAL PERCEPTION FOR THE BLIND THROUGH AN ACOUSTIC SENSOR

Leslie Kay, Ph. D.; Garry Hornby, M.A.; Nora Kay, B.A.; Marion Satherly; and **Stephen Bellamy**
University of Canterbury, School of Engineering
Christchurch, New Zealand

A new design of acoustic spatial sensory aid has been used in a program for training totally blind school children to perceive objects in their near space. The sensor, shown in helmet form (Fig. 1) for gymnasium use, provides a narrow central field of view of 10 degrees having a resolution capability of 4 degrees together with a wide-angle peripheral field of view of 60 degrees. The maximum sensing range can be adjusted from 0.5 meters to 5 meters. A distance code of 5000 H, representing the maximum chosen range, is used similar to the earlier binaural sensory aids (Sonicguide™). Object recognition features are enhanced in the central field relative to the peripheral field, enabling a user to explore objects in greater detail. At the same time, any object motion in the peripheral field immediately demands the user's attention. This generally takes the form of head turn towards the new spatial event for more detailed observation. The generation of flow patterns experienced in the binaural sensory aid has been retained in a modified form.

Tests have been carried out (using sighted students under blindfold) to determine the accuracy of location of objects, the resolution of two objects at the same radial distance, the location accuracy of a discontinuity (edge) in an object space, and the discrimination between different objects in the viewing field both at the same and different radial distances.

These tests have led to the design of a teaching program for use in a school setting where a trained teacher guides a blind child through a series of 40 lessons. The lessons cover acquisition of reaching and locomotion skills related to various aspects of

spatial awareness enhanced relative to that using only natural cues. Data using an N = 1 experimental design is being collected to determine the rate of learning and the extent to which this transfers to later lessons.

The results to date suggest that the approach now being used could be integrated into a spatial awareness training program for blind persons. Its influence on methods of mobility training are being explored ■

FIGURE 1
A "Trisensor" (binaural system with three receiving channels) totally enclosed in a lightweight cycle helmet. No cables are attached so as to allow a blind child complete freedom to play in a gymnasium, learning important spatial concepts. The auditory outputs are from special miniature speakers fitted in the helmet.

PUBLICATIONS OF INTEREST

Our "Publications of Interest" pages list selected articles, books, and reports dealing with the following subject areas: Bioengineering, Biomechanics, General (Rehabilitation), Orthotics, Prosthetics, Sensory Aids, Spinal Cord Injury, and Surgery (Amputation). Most of the articles cited are selected from journals subscribed to by the Office of Technology Transfer (OTT) Reference Collection, while others have been obtained directly from the authors after the works had been abstracted in Bioengineering Abstracts and/or Excerpta Medica, or were cited as references and reviews in other source documents.

To obtain a copy of a specific article, readers are advised to direct inquiries to the author. The name and address of the author to be contacted appears at the end of each journal listing. In most instances, reprints of recent papers are available free of charge from authors.

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Functional Walking in Paralyzed Patients by Means of Electrical Stimulation, E. B. Marsolais, and R. Kobetic; Clin. Orthop. & Rel. Res., 175:30-36, May 1983. (CONTACT: E. B. Marsolais, Motion Study Lab., Veterans Administration Medical Center, Research Bldg. K-205, 10701 E. Blvd., Cleveland, Ohio 44106, U.S.A.)

Standing and Walking for the T6 Paraplegic, A. Duffus and J. Wood; Physiother., 69(2):45-46, Feb. 1983. (CONTACT: A. Duffus, Dept. of Physiotherapy, Regional Spinal Unit, Hexham General Hospital, Hexham, Northumberland, England)

Wheelchair III: Report of a Workshop on Specially Adapted Wheelchairs and Sports Wheelchairs, San Diego, Calif., March 25-27, 1982. Sponsored by Veterans Administration Rehabilitation Research and Development Service and Rehabilitation Engineering Society of North America, September 1982, 67 pp. RESNA, 4405 East-West Highway, Bethesda, MD. 20814.

Wheelchair Transfer Board, A. E. Aaron; Brit. J. Occupat. Ther., 46(3):82, Mar. 1983. (CONTACT: A. E. Aaron, Joyce Cockram Day Hospital, West Suffolk Hospital, Bury St. Edmunds, U.K.)

Wheelchairs and Appliances, D. H. Bossingham; Clin. in Rheum. Dis., 7(2):395-415, Aug. 1981. (CONTACT: D. H. Bossingham, Mary Marlborough Lodge, Nuffield Orthopaedic Centre, Headington, Oxford OX3 7LD, England)

SURGERY

Amputations for Vascular Insufficiency, P. Netz, A. Stark and H. Ringertz; Pros. & Orthot. Intl., 7(1):9-14, Apr. 1983. (CONTACT: P. Netz, Dept. of Orthop. Surgery, Danderyd Hospital, S-182 88 Danderyd, Sweden)

The Psychological Aspects of Amputation Surgery, S. H. Alpert; Orthot. & Pros., 36(4):50-56, Winter 1982-1983. (CONTACT: S. H. Alpert, 5962 Cherry Crest Drive, West Bloomfield, Michigan 48033, U.S.A.)

Books and reports should be obtained from the publishers. The name and address of the publisher, and the price, appear with the publication title.

The books, journals, and reprints listed in "Publications of Interest" may be examined or used for study at the OTT premises, but do not circulate. Individuals planning to visit the Rehabilitation R&D Reference Collection are advised to write or telephone in advance to Ms. Lily W. Hom, Technical Information Specialist, Office of Technology Transfer, Rehabilitation R&D Reference Collection, 252 Seventh Avenue, New York, New York 10001. Callers using the Federal Telephone System should call FTS 660-6659 or 6670; the commercial numbers are (212) 620-6659 and 6670.

Sponsor Index of Agencies, Organizations, and Institutions

Since individual progress reports are presented in the main text under the appropriate headings of Prosthetics/Amputation, Spinal Cord Injury, and Sensory Aids, this index is provided to enable the reader to see at a glance the kinds of research in rehabilitation done by each organization which made progress reports available to this publication.

Department of Health and Human Services, National Institutes of Health, Musculoskeletal Diseases Program*

Stephen L. Gordon, Ph. D., Program Director

**A program of the National Institute of Arthritis, Diabetes, and Digestive and Kidney Diseases, NIH, Bethesda, Maryland 20205, Building 31, Room 9A04. Tel. (301) 496-3583.*

Department of Health and Human Services, National Institutes of Health, Physiology and Biomedical Engineering Program

Americo Rivera, Jr., Ph. D., Program Administrator

This is a program of the National Institute of General Medical Sciences (NIGMS), which is located in Bethesda, Maryland 20205.

Leo H. von Euler, M.D., is the acting Director. W. Sue Badman, Ph. D., is the Chief, Biomedical Engineering and Instrument Development Section.

National Science Foundation 1800 G. Street, Washington, D.C. 20550 Science and Technology to Aid the Handicapped

Lawrence Scadden, Program Director

Department of Education
National Institute of Handicapped Research
Division of Rehabilitation Engineering

Richard R. Leclair, Acting Division Director

Rehabilitation Engineering Center
Case Western Reserve University
Cleveland and Metropolitan General/
Highland View Hospitals
Department of Orthopaedics
3395 Scranton Road, Cleveland, Ohio 44109

P. Hunter Peckham, Ph. D., and Alvin A. Freehafer, M.D., Co-Directors

The focus of research activities in the Case Western Reserve University Rehabilitation Engineering Center is directed toward restoration of upper limb function. Projects reported in this period include restoration of motor function through functional electrical stimulation, electrotactile stimulation for sensory augmentation, and evaluation of abnormal motor control.

Rehabilitation Engineering Center
Children's Hospital at Stanford
520 Willow Road, Palo Alto, California 94304

Maurice LeBlanc, Project Director

The Rehabilitation Engineering Center has been at the forefront of comprehensive service delivery since its beginning in 1974. When the research program was added in 1977, it has a broad, established base of clinical expertise to draw on. All client services are provided on a fee for service basis and are strictly accounted for separately from research activities. The close proximity of both programs has allowed a synergistic partnership to develop between research and service. The Center has a number of research projects which reflect needs identified in clinical services — needs which have been shown to be of national importance.

The focus of NIHR-sponsored research activities at the Center is "Controls and Interfaces for Communication and Other Systems for Severely Disabled People". This includes projects in the areas of Communication and Control, Seating and Postural Control, and Orthotic Control. Education and training activities and information dissemination have also been target areas.

Rehabilitation Engineering Center
Cerebral Palsy Research Foundation of Kansas, Inc., in cooperation with Wichita State University, College of Engineering, 2021 North Old Manor, Wichita, Kansas 67208

John F. Jonas, Jr.; John H. Leslie, Jr.; and Roy H. Harris, Co-Directors. Leonard L. Anderson, Director of Engineering.

The charge of the Rehabilitation Engineering Center at Wichita, Kansas, is to improve the vocational prospects of the severely disabled. The population whose needs it proposes to investigate are those who have significant physical disabilities and normal to near-normal intelligence. The Center proposes to apply the expertise of rehabilitation engineering to the barriers confronting such disabled persons as they seek two of the most fundamental rights — a job and a place to live.

Rehabilitation Engineering Center
Harvard University/Massachusetts Institute of Technology
77 Massachusetts Avenue, Cambridge, Mass. 02139

William Berenberg, M.D., Director

The Harvard-Massachusetts Institute of Technology Rehabilitation Engineering Center has 11 years of experience as a closely coupled clinical and engineering setting for short-term as well as long-term research on behalf of patients with physical disabilities, and has served as a regional consultation center for objective evaluation of the consequences of both conservative treatment and surgical therapy. The clinical center of the Harvard/Massachusetts Institute of Technology Rehabilitation Engineering Center is Children's Hospital Medical Center. Participating organizations include Children's Hospital Medical Center, Harvard Medical School, and Massachusetts Institute of Technology.

The research program consists of a number of interrelated projects consistent with the central objective which is Measurement of Human Performance Through Instrumentation for Purposes of Rehabilitation.

Rehabilitation Engineering Center
University of Michigan
208 Lay Automotive Laboratory
Ann Arbor, Michigan 48109

John W. Melvin, Ph. D., Director; David H. Hardan, M.S., Project Manager; Jolan Cossairt, M.A., Project Editor/Writer

The fundamental goal of the university of Michigan Rehabilitation Engineering Center (UM REC) is to improve the mobility of severely disabled persons through the increased use of personal licensed vehicles. The task of driving, and the system of vehicles, roadways, and drivers are complex and yet common to everyday living. To enable more severely disabled individuals to have the personal mobility that comes from driving, a variety of areas related to the driver, the vehicle, the roadway, and the regulation of the system must be studied.

Because of the interaction of the disabled driver with the rest of the driving population, considerations must be given to minimum driver performance levels, vehicle adaptive modifications which are safe and effective, and occupant protection systems that are specialized to meet the needs of the disabled driver. Such considerations lead to concern over the physiological, psychological, and ergonomic characteristics of the disabled driver, to the design and evalulation of adaptive equipment, and to the evaulation and training of the disabled driver.

Rehabilitation Engineering Program
Northwestern University
345 East Superior Street
Chicago, Illinois 60611

Dudley S. Childress, Ph. D., Director; Edward C. Grahn, Associate Director

The Rehabilitation Engineering Program at Northwestern University notes that Dr. Clinton L. Compere has retired as Co-Director of their research programs and that Dr. Dudley S. Childress is now Director of NUREP. Edward C. Grahn is Associate Director.

Rehabilitation Engineering Center
Rancho Los Amigos Hospital
7601 E. Imperial Highway, Downey, California 90242
Donald R. McNeal, Ph. D., and Robert L. Waters, M.D., Co-Directors

The Rehabilitation Engineering Center is located on the grounds of Rancho Los Amigos Hospital, a teaching hospital of the University of Southern California and one of seven hospitals administered by the County of Los Angeles. The hospital is a 475-bed facility devoted entirely to acute rehabilitation care that provides an effective and unique location for the development of rehabilitation technology.

During the 12-year history of the Center, functional electrical stimulation has been a major core area of research. Initial effort focused on development of a surgically implantable peroneal nerve stimulator to correct footdrop, a common deformity of stroke patients. From that beginning, a comprehensive program of research has evolved that presently incorporates (i) basic studies that contribute to a more complete understanding of neuromuscular stimulation and (ii) clinical research that helps to define the clinical applications of electrical stimulation for the rehabilitation and restoration of function in persons with neurological and/or skeletal impairments.

A second major area of research has been quantative analysis of gait and human motion. Projects in this area are centered in the Pathokinesiology Laboratory, one of the foremost human function laboratories in the world. The major goal of the Laboratory's research, as it has been since its inception in 1969, is to develop and apply objective methods of measuring functional gait and motion deficits in patients with neuromuscular impairments. The measures are then used to assist the clinician, engineer, and prosthetist in determining treatment techniques and assessing the performance of assistive devices.

Rehabilitation Engineering Center
Neurofunction Laboratory
University of Texas Health Science Center
Dallas, Texas 75235

Alfred R. Potvin, P.E., Ph. D.; Vert Mooney, M.D.; George Wharton, M.D.; Ray Dabney, B.S.O.T.; George V. Kondraske, Ph. D.; and Ronald Tintner, M.D.

Investigators in the Dallas/Fort Worth "metroplex" with interests in rehabilitation engineering have organized a four-institution consortium consisting of the University of Texas at Arlington, the Dallas Rehabilitation Institute, the University of Texas Health Science Center at Dallas, and the Dallas Rehabilitation Foundation. This consortium was recently awarded a grant by the Na-

tional Institute of Handicapped Research to establish a Rehabilitation Engineering Center for functional assessment of the handicapped. With primary funding from this grant, the group plans a major expansion of the functions of the Neurofunction Laboratory, which for more than two decades has been developing and evaluating batteries of tests for assessing handicapped individuals. The range of conditions covered will be broadened and the applicability, reliability, and effects on results of such factors as age, gender, learning, and handedness will be studied.

The evaluation studies of the expanded laboratory system will begin this year at the Health Science Center. By the end of the next year, an identical system is to be in operation at the Rehabilitation Institute. The two systems will be used to carry out studies to determine the applicability of tests to patients with a wide range of handicaps.

The Center's mission is to develop a reliable, valid, and objective method of assessing human functions that can improve the way in which clinical trials are carried out, analyzed, and interpreted. With instrumented assessment devices, clinicians may be able to develop more effective medical devices and treatments, and reduce or eliminate the use of ineffective or placebo-like treatment. The result should be to improve the rate and extent of recovery toward normal function, enhance a patient's quality of life, and reduce direct and indirect costs to patients and society. The Center is working closely with community, state, and federal rehabilitation agencies; the biomedical industry; and professionals in the fields of science and engineering.

Texas Rehabilitation Engineering Center
at The Institute for Rehabilitation and Research (TIRR),
in the Texas Medical Center
1333 Moursund Ave., Houston, Texas 77030

Thomas A. Krouskop, P.E., Ph. D., Program Director; Jesse H. Dickson, M.D., Program Co-Director

The efforts of the Texas Rehabilitation Engineering Center were primarily devoted to studying the effects of pressure on human tissue, and specifically addressed the third NIHR mission outcome of preventing or minimizing personal and family, physical, mental, social, educational, vocational, and economic effects of disability.

Secondarily, the Center activities addressed the first and second NIHR mission outcomes which were (i) identifying and eliminating the causes and consequence of disability, and (ii) maximizing a healthy physical and emotional status of handicapped persons, their functional ability, self-sufficiency, self-development, and personal autonomy.

Development of a more complete understanding of how pressure sores develop, with emphasis on using this knowledge to prevent pressure sores from developing, and provision of increased physical mobility for independent living and work performance, are the key rehabilitation engineering problems which have been addressed in the Texas REC for the past 10 years.

NeuroMuscular Research Laboratory
Children's Hospital Medical Center
Boston, Massachusetts 02115
and
Liberty Mutual Research Center
Hopkinton, Massachusetts 01748

Carlo J. De Luca, Ph. D., Director

Our efforts can be delineated into the following areas:

1. Clinical Rehabilitation: *For the past 4 years, our laboratory has been developing a new treatment technique for improving the quality and quantity of joint movements in patients affected with muscle spasticity. The technique involves modulation of the sensory input of the skin by applying topical anesthesia.*

2. Muscle Contraction: *This program involves several investigations directed at understanding how the central nervous system controls individual as well as groups of muscles in performing different types of contractions. This knowledge is critical to the development of clinical procedures for treating weak and dysfunctioned muscles.*

3. Muscle Fatigue: *For the past 5 years, we have been developing and testing a technique for objectively measuring the rate of fatigue of contracting muscles. An automated device called the Muscle Fatigue Monitor has been designed and constructed in our laboratory. This device has the potential of providing an objective measure of the physiological component of muscle fatigue, removing the psychological component which can commonly lead to seriously erroneous subjective evaluations.*

4. Prosthetics Control: *For the past 9 years, we have continued to pursue the development of a recording electrode which may be implanted around a severed peripheral nerve. The purpose of this endeavor is to continuously detect signals from the surface of a nerve that are associated with the functionally distinct limb movements. Such signals, when transported outside the body, may be used to control multiple-degrees-of-freedom prostheses or other external devices.*

The NeuroMuscular Research Laboratory consists of two units, one located in the Orthopaedic Surgery Department of Children's Hospital Medical Center, Boston, Massachusetts, and the other at the Liberty Mutual Research Center, Hopkinton, Massachusetts. The two units, although physically separated, operate and are administered as one laboratory.

During 1982, seven research scientists from Europe spent some time working in our Laboratory. We are grateful for their contribution. The Laboratory receives its major financial assistance from Liberty Mutual Insurance Company. The National Institute of Handicapped Research also supplies some financial assistance. Minor financial assistance has also been received from four Swedish institutions. Their support is gratefully appreciated.

Veterans Administration Department of Medicine and Surgery Rehabilitation Research & Development Service

Margaret J. Giannini, M.D., Director

Hines Rehabilitation Research & Development Center
Edward Hines, Jr., Hospital
Hines, Illinois 60141

J. Trimble, Ph. D., Acting Chief; C. J. Robinson, D. Sc., Acting Assistant Chief

Overview: *Fiscal Year 1982 was a period of intense activity at the Hines Rehabilitation R&D Center, especially in the biomechanics field. We completed installation and testing of a pulsed ruby laser. This instrument allows us to examine stresses that cannot be measured by any other technique. It will prove valuable in studying a wide range of stress-induced phenomena ranging from pressure sores in paralyzed patients to stress fractures in wheelchairs.*

Also in the area of biomechanics, we are making great progress in computer-aided design and simulation. We now have the facility for the computerized design and testing of wheelchairs. This allows us to predict failure modes in new designs without the expense and effort of full-scale testing.

In the area of applied neurophysiology, we have developed collaborations with the Pritzker Institute of Medical Engineering, to explore how Functional Electrical Stimulation (FES) can best be used to aid the paralyzed veteran.

We have also strengthened our efforts in blind rehabilitation. A new study on the problem of low vision will use computer techniques to show how the world looks to people who are visually impaired.

Significant progress has also been made in the development of new aids for disabled persons. Our technical development laboratory has produced new devices for communication and environmental control.

Our research model shop has developed a novel wheelchair design that functions as both a lift and a wheelchair.

Rehabilitation Research & Development Center

Palo Alto VA Medical Center
Palo Alto, California 94304

Larry J. Leifer, Ph. D., Director

Program Directors and **Medical Program Directors** and the VA Rehabilitation Research and Development Center at Palo Alto Veterans Administration Medical Center are the following:

Felix E. Zajac, Ph. D., Nerve-Muscle Systems; **Leslie J. Dorfman, M.D.,** Nerve-Muscle Systems Medical Program; **Dennis R. Carter, Ph. D.,** Orthopaedic Biomechanics; **John Csongradi, M.D.,** Orthopaedic Biomechanics Medical Program; **Larry J. Leifer, Ph. D.,** Human/Machine Interaction; **Robert Chase, M.D.,** Human/Machine Interaction Medical Program; **Patricia A. McCarty,** Staff Assistant.

Two recreational devices which have been developed here and have moved "out the door" and into successful commercial production (the Arroya Ski Sled for paraplegics, currently manufactured by Beneficial Designs of Santa Cruz, California; the Handbike, also for paraplegics, currently manufactured by Recreational Mobility of Elmira, Oregon); two mobility devices developed here and under negotiation with private manufacturers for production rights (Smart Wheelchair, a head-controlled wheelchair for use by quadriplegics, already in daily use by one disabled user; Alexis, a high-technology wheelchair for use by paraplegics, which incorporates five major technological advances over today's standard wheelchairs); and several devices, including a spinal transport unit and a reading aid for the blind, which have already received queries regarding production agreements from potential manufacturers.

The following progress reports from VA facilities, and organizations under contract with the VA, are identified by geographical location in alphabetical order.

REPORTS FROM OTHER NATIONS

The following progress reports have been received from Argentina, Canada, Great Britain, Japan, and New Zealand.

ARGENTINA

Instituto de Mecanica Aplicada
Servicio Naval de Investigacion y Desarrollo y Consejo Nacional de Investigaciones Cientifical y Tecnicas.
Base Naval Puerto Belgrano
8111 - Argentina

L. C. Nava (Research Engineer), and P. A. A. Laura, Ph. D. (Research Scientist)

The authors comment that, "With regards to research and development in the rehabilitation engineering field in South America it may be worthwhile to recall that data presented at the Second World Congress of ISPO in 1977 showed all of South America as having no rehabilitation engineering R&D centers at all (the total number in the world was put at 561, of which North America had 267, Europe 233, Africa 4, Asia 36, and Australia 21)."

CANADA

Royal Ottawa Regional Rehabilitaton Centre
Rehabilitation Engineering
505 Smyth Road, Ottawa, Ontario K1H 8M2

Micheál D. O'Riain, Ph. D., Director of Rehabilitation Engineering

Rehabilitation Engineering Personnel** — Director — **Micheál D. O'Riain, Ph. D.;** Rehabilitation Engineer — **Jacques Sibille, M.A.Sc.;** Computer Engineer — **Louis Goudreau, B.Sc.;** Mechanical Technologist — **Gilbert Layeux;** Electronic Technologist — **Gordon Evans;** EMG Technologist — **Janina Browarska;** and Secretary — **Malinda Provost.

*In addition to the above personnel, the gait laboratory team includes two physiotherapists and three physiatrists who are involved in the clinical and medical operations of gait analysis. These are: **Jennifer Nymark, M.Sc.A.,** Senior Physiotherapist; **Suzanne Balmer, B.Sc. (PT)** (Oct. 1982 - Apr. 1983); **Marlene Eckstrand, Dip. P.&O.T., B.Sc.** (Apr. 1983 - Oct. 1983); **R. Fisher, M.D., F.R.C.P. (C); J. Latter, M.D., F.R.C.P. (C),** and **R. Simard, M.D., F.R.C.P. (C).***

A major part of the work of Rehabilitation Engineering is the design and construction of special aids for handicapped persons. For this, we are indebted to other disciplines including: Physiotherapy, Occupational Therapy, Communication Disorders, Leisure and Recreation, Nursing, Prosthetics and Orthotics, Psychology, etc., for providing many suggestions and requests for devices, and for assisting us during all phases of design, construction, and evaluation.

In this report we give brief descriptions of the major devices designed and constructed in Rehabilitation Engineering. All of the devices described are in regular use by patients and therapists attached to this centre. We expect that many of the devices will be of interest to other centres. We will be happy to provide additional information to any centre requesting it.

GREAT BRITAIN

Orthotics and Disability Research Centre
Derbyshire Royal Infirmary
Derby DE1 2QY, Great Britain

Dr. D. J. Pratt, Technical Director

The Orthotics and Disability Research Centre at Derbyshire Royal Infirmary, Derby, England, is a small department with a service commitment for the solution of difficult orthotic problems and the provision of research into orthotics and disability in general, under the general direction of Dr. D. J. Pratt.

Progress reports for three projects, as of July, 1983, are presented in this issue.

University of Strathclyde
Bioengineering Unit
Wolfson Centre
106 Rottenrow, Glasgow G4 ONW

Prof. J. P. Paul, Head of Department

JAPAN
Agency of Industrial Science and Technology
Ministry of International Trade and Industry
1-3-1, Kasumizaseki, Chiyoda-ku
Tokyo, Japan

NEW ZEALAND
University of Canterbury, School of Engineering
Christchurch, New Zealand

Leslie Kay, Ph. D.; Garry Hornby, M.A.; Nora Kay, B.A.; Marion Satherly; and Stephen Bellamy

Personnel Index

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